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## ALUMINUM HONEYCOMB SANDWICH DEVELOPMENT

Contract No. AF 33(600)-23626

### HEXCEL PRODUCTS CO.

A Division of the California Reinforced Plastics Company  
901 Sixty-First Street, Oakland 4, California

Prepared for  
**UNITED STATES AIR FORCE**  
Air Materiel Command  
Industrial Resources Division  
Production Development Unit  
Wright-Patterson Air Force Base, Ohio

**FINAL REPORT**

**ALUMINUM HONEYCOMB SANDWICH DEVELOPMENT**

**R. B. Runkle**

**H E X C E L P R O D U C T S C O.**  
a division of the  
**California Reinforced Plastics Co.**  
951 61st Street  
Oakland, California

**September, 1954**

**Contract Number AF 33(600)-23626**

Air Materiel Command  
Industrial Resources Division  
Production Development Unit  
**UNITED STATES AIR FORCE**  
Wright Patterson Air Force Base, Ohio

**FOREWORD**

This report was prepared by the Hexcel Products Company, a division of the California Reinforced Plastics Company in accordance with Air Force Contract Number AF 33(600)-23626. This contract was initiated and sponsored by the Production Development Unit of the Industrial Resources Division, Air Materiel Command.

## ABSTRACT

Recommendations for optimum materials and processes in the manufacture of flat aluminum honeycomb sandwich are made on the basis of comprehensive studies of a large number of independent variables.

The effects of weight and distribution of the adhesive on bond strength are described, for one particular test vehicle, "FM-47" adhesive (manufactured by the Bloomingdale Rubber Co.). Less comprehensive studies are carried out on other adhesives to allow extrapolation. Three adhesives are evaluated in peel and flatwise tensile-strength tests at elevated temperature.

Optimum methods for the application of liquid adhesives to honeycomb and facings are developed from experimental studies and surveys of comparable operations in other industries. Proposed design layouts of high-production and medium-production cleaning and priming equipment for facings, and of priming equipment for core, are presented. The technical and economical advantages of processing facings in the strip form are discussed. Corrosion-resistant materials for cleaning equipment are evaluated.

A number of physical and chemical cleaning variables, as well as the effects of storage of aluminum cores and facings, are studied.

The effects of curing time, temperature, and pressure on bond strength are evaluated. Methods for correcting or compensating for press warpage and core thickness irregularities, based on experimental studies and survey data, are set forth.

The effects of honeycomb cell-size and thickness-sizing method on bond strength are evaluated.

An exploratory study of the significance of sandwich bond strength as a design criterion is described.

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## INTRODUCTION

The use of adhesive-bonded aluminum honeycomb sandwich construction in aircraft has expanded rapidly in the past few years, and promises to continue this expansion at an even greater rate. The specialized theory and practical technology of this type of bonding, in combination with its relative newness, sometimes prevent manufacturers from achieving full utilization of its advantages. Many firms who have achieved control of their processes after years of development and training are justifiably reluctant to make changes which might jeopardize this control.

Although experience and the exchange of information have resulted in steady progress in the technology of sandwich bonding, there has been a need for a concentrated effort directed toward the isolation and control of critical production variables, allowing increased production of uniformly high quality materials at lower cost, and with less dependence on individual skills.

The basic objectives of USAF Contract No. AF 33(600)-23626 are intended to fill the need for such an advancement. These objectives are listed as follows:

- A. Development of improved fabrication methods, amenable to an economical expansion potential in the event of total mobilization.
- B. Reduced production costs.
- C. Improved quality level of the end item.

The scope of the "statement of work" of the contract may be outlined more specifically as follows:

1. A comprehensive preliminary survey covering the latest practices and methods used in the production of adhesive-bonded sandwich materials.
2. Development of a dependable and economical cleaning and priming method for the faying surfaces of sandwich composite.
3. Determination of the most practical adhesive system for general production use. This calls for evaluation of cost, availability, physical properties, and ease of application and cure. Heat-resistant adhesives in the range from 200° to 500° F are included.
4. Evaluation of honeycomb cell size with respect to production costs, physical properties, and adhesive weight in sandwich composites.

Introduction, Continued

5. Development of a production method for securing uniform platen curing pressure on flat honeycomb sandwich composite.
6. Collaboration with contractors who are engaged in evaluation of non-destructive testing devices through consultation and the furnishing of test specimens.
7. At the conclusion of the foregoing developments, to:
  - a. Evaluate the consistency of the quality of honeycomb composite produced by the improved methods.
  - b. Determine production cost savings.
  - c. Recommend tolerance standards for core thickness, platen flatness, and curing-cycle variables.
  - d. Prepare an efficient production-layout plan.

In this final report under the contract, the work has been presented in three sections. Section I contains the results of individual studies of process and material variables. Section II contains the results of individual studies of equipment variables, extrapolated to include the development of high-production techniques. Section III contains a general discussion of sandwich bonding practices, based on documented experimental results in this and other projects, and on survey information gained from discussions with manufacturers.

The control fabrication and test conditions, as well as the final drafts of proposed specifications for automatic processing equipment, have been included in separate appendices. The last appendix contains the results of exploratory studies of the significance of bond strength as a design property.

## SECTION I

### PROPERTIES OF THE BOND, AS INFLUENCED BY MATERIAL AND PROCESS VARIABLES

#### SCOPE; DEFINITION OF TERMS:

This section presents the results of studies of the effects of individual material and process variables on aluminum honeycomb sandwich bond strength. These evaluations were used to define optimum process conditions which could be applied to the development of dependable and economical production techniques. Studies of individual variables have been grouped into six divisions within this section.

The majority of the evaluations discussed in this section were based on the results of peel tests and flatwise tensile tests performed on specimens cut from laboratory-size sandwich panels. The peel-testing device used in the project was a specially built, four-inch drum-type machine, driven by a Tinius-Olsen testing machine. The peeling torques in inch-pounds, required to remove the facings from three-inch-wide specimens, were recorded autographically. One-inch-square specimens from the panels were bonded to aluminum blocks and pulled in flatwise tension, in apparatus similar to that used by Forest Products Laboratory (reference 34). In some instances, the peel and tensile-strength values were divided by the unit weight of adhesive in the panel to obtain "specific" strength values which were equivalent to "strength-weight" ratios.

Since it was not feasible to duplicate the evaluations of individual material and process variables in several adhesive-bonding systems, one system was used as a test vehicle, and the results were augmented with exploratory evaluations of other adhesive systems. The choice of a suitable adhesive system for use as a test vehicle was based on the results of a "Survey of Existing Methods", conducted in May, 1953. It was found that fabric-reinforced bonds were used by almost every honeycomb sandwich manufacturer. Usually the fabric was added in the form of a cloth-support in a dry film of adhesive. Two "supported film" or "tape" adhesive systems were in common use at the time of the survey. The majority of the collected information, relating to process variables and physical properties, was found to apply to the "FM-47" supported film and liquid system, supplied by the Bloomingdale Rubber Company of Chester, Pennsylvania. It was decided that this system should be used as a control vehicle in the project, in order to take advantage of the maximum amount of existing practical technology.

Although the trends observed in the "FM-47" system are generally representative of resin-plasticized phenolic adhesives as a class, quantitative results based on its use cannot be applied directly to other formulations within the class. There is limited correlation with results based on other classes (particularly the "epoxy" resins).

Detailed discussions of the conditions of fabrication and testing have been placed separately in Appendices I and II respectively. Where exceptions to the control procedures occurred, the results have

Section I, Continued

been noted accordingly. In most cases, an abbreviated listing of the control conditions is included with the results of each evaluation.

The nomenclature of the adhesive bond used in this report includes the following: "Core prime" as used here implies a relatively light coating of adhesive applied to the top edges of the cell walls, for augmenting the strength of a film-type bond. A "bead" or "heavy bead" refers to a heavy deposit of core prime, applied in such a way as to extend over the tops of the cell walls, and is normally used in a "liquid only" bond. "Film" refers to a layer of dried or semidried adhesive of uniform thickness. "Supported films" or "tapes" are those films which contain a fabric reinforcement (glass scrim cloth, cheesecloth, etc.). "Unsupported films" are composed of adhesive alone, with no fabric reinforcement. "Facings" or "skins" are the sheet aluminum surfaces of the panel. A "facing prime" or "skin prime" is a light coating of adhesive used to protect the cleaned facings from contamination and to improve adhesion to the facing.

A: EFFECT OF WEIGHT AND LOCATION OF ADHESIVE ON BOND STRENGTH:

The individual variables studied in this phase included core prime weight, tape weight, cell size, core prime depth, and weight of facing prime.

1. Core Prime Weight, Tape Weight, and Cell Size:

The first major experimental program undertaken in this phase, and in the project itself, was a comprehensive, combined study of the effects of core prime weight, tape weight, and cell size on bond strength, as reflected in room-temperature peel and tensile strength. This program involved a large number of panels and extended over a period of several months. Dried, uncured weight of core prime was made the independent variable; tape weight and cell size were parameters. Comprehensive evaluations were performed in the 1/8-inch and 1/4-inch cell sizes, using a wide range of tape weights. Evaluations were performed in the 3/16 and 3/8-inch cell sizes with one tape weight only.

Core-prime weight was adjusted by varying the number of "passes" through a roller-coating machine. A constant "doctor" or metering gap of 0.030 inches was used in priming all of the cores used in the "Adhesive Weight" program. The majority of the cores were primed in a 52-inch, 1/4-hp, electrically driven "veneer coating" machine, having a four-inch-diameter, rubber-covered applicator roll. Some of the panels made later in the program were made from cores primed in a smaller, hand-operated machine. Discussions of these machines are included in Section II - Part A, and Appendix I.

The prime depth applied at a 0.030 inch doctor-gap setting on the power-driven machine varied locally from approximately 0.010 inches to 0.035 inches. The depths applied in the hand-operated machine were found to be somewhat less, but the cores primed in the two machines were considered interchangeable for control purposes in the "Adhesive

I - A, Continued

"Weight" program. The cores primed in the two machines could not be considered interchangeable where "prime depth" was studied as an independent variable, however. See Part 2 of this discussion, entitled "Core Prime Depth".

The effects of adhesive weight and cell size are shown in tabular form in Table 1, and graphically in Figures 1 through 18, at the end of this discussion. Note that the tabular presentation shows the type of failure as well as the panel serial numbers and the lowest readings. Panels in this table are grouped by tape weights in each cell size, and are arranged in increasing order of core-prime weight, within each tape-weight group.

The "specific" flatwise tensile and peel values shown in the tables and graphs were obtained by dividing the observed strengths by the total cured adhesive weight, in pounds per square foot of panel. The specific values may be interpreted as strength-weight ratios, or bond efficiencies. The dimensions of these quantities have no particular significance. It should be noted that the "specific" strength or strength-weight ratio of the bond is not the most important criterion in the selection of an optimum bonding system for a given sandwich construction. The primary purpose of the bond is to permit the full capabilities of the core material and the facings to be realized. After the strength requirements of the bond for a particular combination of core and facings have been ascertained, it is then desirable to seek a bonding system which consistently meets these requirements without imposing a weight or cost penalty.

Figures 1 through 6 show actual and specific tensile strengths as a function of dried, uncured core-prime weight, uncured tape weight, and cell size. The next six families of curves, Figures 7 through 12, show actual and specific peel strengths.

Figures 13 and 14 are interpolated from the original peel and tensile curves, and show cell size as the independent variable, at a tape weight of 0.079 lbs. per square foot.

Figures 15 through 18 show peel and tensile strengths in two cell sizes as a function of total cured adhesive weight in the bond. These curves were derived from the original peel and tensile curves by computing the total bond weight at selected values of uncured tape and core prime weights, on the assumption that the cured weight of the sum of all adhesive components was 0.85 times their uncured weights. (This figure is an average based on a large sampling.)

Increases in adhesive weight in the form of either core-prime weight or tape weight, brought about increases of peel strength and flatwise tensile strength. An exception to this rule is shown in Figure 7, where the dotted portions of the 1/8 inch cell, peel curves tended to reach a maximum. These dotted portions are known to represent a condition wherein the adhesion to the facing itself becomes a limiting factor. It is doubtful that adhesion to the facings actually drops off as core-prime weight is increased, as the dotted curves imply. It is more likely that

I - A, Continued

the curvatures resulted from unintentional variations in the effectiveness of the cleaning operation. As the dotted portions represent very high peel strengths, the true shape of these curves is of little importance.

The peel strengths of the panels marked with asterisks, in Table 1, were left off the graphs showing peel strength vs. core-prime weight. The peel strengths of these panels appeared to be lower than normal and the specimens showed relatively high percentages of adhesion failure at the surface of the facing. The fabrication dates of these panels fell into two periods when the cleaning process appeared to be out of control. The loss of control is fully discussed in Part F of Section I, under "Preparation of Facings".

The specific flatwise tensile curves indicate that a tape weight of the order of 0.05 lbs/sq.ft. gives the highest strength-weight ratio for both the 1/8-inch and 1/4-inch cell sizes, at core-prime weights in excess of 0.02 lbs/sq.ft. The "specific peel strength" curves indicate that the efficiency of the bond in peel strength continues to increase as tape weight is increased, particularly at low values of core-prime weights. In general it can be concluded that increases in either core-prime weight or tape weight bring about increases in peel and flatwise tensile strengths, but peel strength is more directly influenced by tape weight.

The effect of cell size can be interpreted indirectly from Figures 5, 6, 11, and 12, and directly from Figures 13 and 14. Both peel strength and tensile strength are nearly inversely proportional to cell size, at any given set of adhesive weight conditions. (An exception to this rule occurs where adhesion to the facing limits peel strength.)

Figures 15 through 18 do not present new data, but show the previous curves in a form which may be more readily interpreted by those who are accustomed to working in terms of total cured adhesive weight. Ordinarily, the cured weight of adhesive in a typical sandwich bond is approximately 0.14 lbs per square foot. These curves show the effect of variations about this value.

With the trends exhibited by Figures 1 through 18 in mind, the reader may more readily interpret the significance of the trends of the types of failures, and of the low readings in Table 1. The system of failure designation used in this project recognized six possible types of failure within the bond itself. (See Appendix II for full description, and photographs of specimens). Although the system was subject to some discrepancy, definite trends were observed. Flatwise tensile failures in the TM-47 system occur between the tape and the core, almost without exception. Low adhesive weights tend to bring about failures in adhesion at the cell walls themselves. Tensile failures in the core material (usually where a 1/8-.0015 core was used in a heavy bond) were not averaged or plotted, since they did not give quantitative data on the

I - A, Continued

effect of adhesive weight, but only indicated qualitatively that the bond was adequate for the core material in question. Peel failures tended to be more randomly distributed throughout the fillet structure within each specimen and from specimen to specimen. Where adhesive weight was high, and/or a small cell size was used, peel failures tended to restrict themselves to the adhesive-to-facing interface. Conversely, low adhesive weights and large cell sizes exhibited peel failures in the proximity of the cell walls. The reader should overlook the panels marked with asterisks when studying trends of peel failures in Table 1.

Because only three or four peel and tensile specimens were taken from each panel, the lowest observed readings (expressed in the table as percents of the mean) are not by themselves statistically valid indications of consistency of quality, but collected results from large numbers of panels exhibited important trends. In each group of panels in Table 1, particularly in the lower tape weights, there is evidence that the lowest observed readings increased in relation to the mean readings as core prime weight was increased, which may be interpreted as an improvement in consistency of quality. There was a considerable upgrading in the low readings (percents) as tape weight was increased. Cell size had no obvious effect on the consistency of quality of the bonds.

Although the use of a supported film weighing approximately 0.05 lbs. per square foot affords optimum "strength-weight" characteristics in flatwise tensile strength, it must be remembered that strength-weight ratio is not the most important criterion. First of all, the bond must be strong enough to develop the full properties of the core material and the facings. A tape weighing 0.05 lbs. per square foot is not necessarily capable of meeting this requirement in any given structure. Secondly, the bonding system as a whole must remain consistent in quality, under reasonable manufacturing conditions. It has been found in the work discussed here, and in Part D of this section ("Curing Cycle Variables") that bonds made from tapes weighing 0.07 lbs. per square foot present significant advantages over bonds made with lighter tapes, in consistency of quality and ease of manufacture. These advantages appear to offset the slight penalty in strength-weight ratio imposed by using heavier tapes.

The lack of experimental coverage of tape weights between the nominal unit weights of 0.05 and 0.08 lbs. per square foot was unintentional. Originally, it was planned to test tapes weighing (nominally) 0.03, 0.05, 0.07, 0.09, and 0.11 lbs. per square foot. The "0.05" and "0.07" tapes were standard items and were to have received the most complete coverage. Although two lots of "0.07" tape were ordered, both were at the high end of the manufacturer's weight limits, giving an average weight of 0.079 lbs. per square foot.

The results have indicated that the fluctuations in tape weight that are currently tolerated in the industry have a significant effect on bond strength. In the course of the project many rolls of supported film, from two different manufacturers, were cut into relatively small pieces of known area and weighed. The following is a

I - A, Continued

tabulation of unit weight of 10 inch by 18 inch pieces, in lbs/sq.ft. observed across the width and down the length of a typical roll of "0.07" supported film of "FM-47":

UNIT WEIGHT OF "FM-47" TAPE, LBS/SQ. FT.			
ACROSS WIDTH			
-----	-----	0.0705	0.0835
LENGTHWISE	0.070	0.065	0.0675
	0.070	0.067	0.0693
-----	-----	-----	-----
	0.070	0.074	0.071
			0.082

Significant weight gradients are in evidence in this roll. Weight gradients have appeared to be particularly obvious at the tag ends of the rolls. It can be concluded that more attention should be given to the control of tape weight, by both the manufacturers and the users of the material.

It is apparent that the average unit weight of a given roll cannot be determined satisfactorily from one coupon taken from the end of the roll. A better determination could be made from the total weight of the roll, divided by the total area, but this would give no indication of local fluctuations or over-all gradients. A further refinement to the weight-control system would be the removal of lateral strips, approximately two inches wide, from each end and from the center of each roll. These strips would be cut into four equal pieces to be weighed individually. The application of statistical quality-control analysis to this sampling method should give a realistic indication of the weight conditions within each roll.

Because the determination of local unit weight on a sampling basis is a time-consuming destructive test, not entirely representative of conditions throughout the roll, consideration should be given to a continuous non-destructive method permitting 100% inspection.

It is suggested that the maximum tolerance on a supported film having a nominal weight of 0.07 lbs per square foot, be made plus 0.01, minus 0.005 lbs. per square foot. (These limits are designed to recognize the practical limitations of existing equipment used in the manufacture of supported adhesive films, and are wider than what would otherwise be specified to assure good consistency of panel quality.)

In specifying a core-prime weight, the designer should note that the addition of a very small amount of adhesive to the unprimed core brings about a striking increase in bond strength. Successive additions of core-prime weight bring about smaller increments of improvement in strength. Although sandwich structures made from unprimed core material would show reduced fabrication costs, the strength-weight

I - A, Continued

efficiency would be below optimum, and there might be some danger of bond deterioration or corrosion from exposure at a later date. No exposure tests were conducted within this project but it is generally believed throughout the industry that priming enhances the resistance of an adhesive bonded structure to corrosion.

Since very light core primes are effective in promoting efficient bonds where a substantial tape weight is used, and since it is impractical to attempt to maintain weight-inspection records on core primes weighing less than 0.01 lbs. per square foot, it is recommended that "complete coverage" be specified in lieu of a given weight in all panels in which maximum bond strengths are not required. Primes applied under such a specification would be presumed to require only one pass through a roller coater and would be subject to visual inspection only. The addition of dye to the adhesive would be mandatory here to facilitate inspection. Where the service requirements on the panel dictate that heavier core prime weights (0.01 to 0.03 lbs. per square foot) be used, the weight should be specified.

The results indicated that if bond strength were the only consideration in the design of a sandwich panel, the smallest possible cell size should be used. Other considerations affecting the choice on honeycomb cell size are discussed in Part "E" of this section.

2. Core-Prime Depth:

An important dimension not considered in the study represented by Table 1 and Figures 1 to 18 is that of core-prime depth. The importance of this variable became increasingly evident as the work progressed, and was quantitatively determined when the project was approximately half completed. Table 2, at the end of this discussion, presents the results of this study. Eight cores in two cell sizes were primed in the hand-operated roller coater (described in Section II-A), at doctor-gap settings of 0.015 and 0.060 inches. These settings were intended to provide extreme conditions which could be compared with the results obtained with the intermediate "control" doctor setting of 0.030 inches, used in the "Adhesive Weight" program. It was later found however, that the depth applied with the 0.060-inch setting was less than the depth applied with the control doctor setting, making it inadvisable to use the control results in the comparison. This incongruity was apparently caused by a change in priming equipment; the majority of cores used in the "Adhesive Weight" program were primed with the power-driven roller coater, not the hand-operated model used in the "Core Prime Depth" evaluation.

The depth of prime on each slice of core, estimated with the aid of a machinist's scale, was from 0.010 to 0.015 inches on the cores primed with the smaller doctor setting, while the range on the deeper-primed cores was from 0.015 to 0.035 inches. The method of estimating these depths was crude, but a more precise method was not justified in view of the fact that the depth within each individual cell varied over nearly the entire range of observed values. Later work indicated that the variations could have been substantially eliminated by using a coater with a special "doctor-blade" metering system, but no such machine was available for use in the "core-prime-depth" program.

I - A, Continued

The peel and tensile results shown in Table 2 are expressed as both "actual" and "specific" strength values; the latter representing strength-weight ratios in effect. Before interpreting these results, it should be noted that the number of coating passes was not constant in the evaluation. The number of passes was doubled on the shallow-primed cores in an attempt to keep the prime weights nominally the same on each cell size, but the deeper primes were nevertheless heavier. The "specific" strengths were substantially higher where the depth was shallow, even though the lighter coatings on these cores would be expected to reduce their strength-weight ratios. The bond strengths on the "shallow" and "deep" cores in each cell size were substantially the same. The strengths developed by the "shallow-primed" cores would undoubtedly have been lower if the number of coating passes had not been doubled, however.

The change in priming equipment mentioned previously in this discussion brought about an indirect confirmation of the results presented in Table 2. Cores primed throughout the latter part of the project displayed shallower prime depths than did the cores primed for the adhesive-weight program. Bond strengths obtained from the later cores were nearly always higher, under any given set of weight conditions, than could be predicted from the results of the "Adhesive Weight" program. The levels of the curves in this program (Figures 1 - 18) were undoubtedly defined by the depth of prime in the cores.

It may be concluded that the use of a shallower core prime would conserve adhesive and minimize the weight of the finished panels but the increased number of coating passes required to achieve a given level of bond strength in a shallow prime system would tend to offset these advantages.

Shallow core primes have one obvious advantage, not specifically evaluated in this project, in that there is much less danger that cell-wall perforations may be blocked off with adhesive, where thin (approximately 3/16 inch) panels are bonded.

Although the increased production cost of applying extremely shallow core primes does not appear justified, it is apparent that a reasonable limit on depth, as well as a set of unit weight limits that is within the practical limits of available equipment, should be defined in specifications for primed core material. With some of the priming equipment currently in use, the depth is very irregular and an accurate determination of the average is nearly impossible. As an interim specification figure, it is suggested that the shortest observed depth be held to a maximum of 1/64 inches. Where optimum equipment (presumed to be a roller coater, metered with a blade) is available, a nominal depth of 0.025 inches should be specified. It should be noted that core prime depths of 1/16 inches have sometimes been called for, apparently in the belief that a large figure is more conservative. Many process specifications call for a given weight, but do not specify depth. The actual depths realized under this type of specification are likely to be excessive, because less effort is required to apply a deep prime of any given weight.

3. Facing-Prime Weight:

An evaluation of the effect of facing prime-weight is presented in Table 3 at the end of this discussion. The bond efficiencies developed from lightly primed (0.003 to 0.008 lbs per sq. ft.) and unprimed facing areas are compared. Two of these conditions were represented in each panel, separated by a line of demarcation drawn on the facings. The extreme conditions, "unprimed" and "heavily primed" were not incorporated in the same panels. The evaluations were duplicated in the 1/8-inch and 1/4-inch cell sizes, with various core-prime and tape weights. The order of presentation in Table 3 is by increasing total cured adhesive weight in each group.

Quantitative comparisons of the two prime conditions are based on the strength-weight ratios ("specific" strengths) on each side of the line of demarcation. Since a lightly-primed area was incorporated in each panel, the specific strength values in the lightly-primed areas were made the denominator, in the two ratios denoted in Table 3 as "None/Light" and "Heavy/Light".

Analyzing the "None vs. Light" results in Table 3, it can be seen that the efficiency of the bond in peel strength was generally lower where no prime was applied to the facing. The facing prime assumed more structural importance in the small cell size and in heavier adhesive lines, where the bond to the core became strong enough to cause failure to occur in adhesion to the face. In the 1/4-inch cell size, the facing prime was less effective in upgrading peel strength-weight efficiency than in the 1/8-inch cell size. Flatwise tensile strength in either cell size showed little or no improvement when a prime was added.

Increasing the facing-prime weight from "light" to "heavy" did not generally improve the efficiency of the bonds in peel strength. Increases in facing-prime weight had no marked effect on flatwise tensile strength in the results shown in Table 3.

The following conclusions can be drawn from the results presented in Table 3:

- (1) The addition of an adhesive prime coat to the surfaces of the facings generally improves the peel strength-weight ratio of the bond but has little effect on flatwise tensile strength.
- (2) The over-all strength-weight ratio of the bond is not increased by using heavy facing primes in preference to light ones.

It is generally believed in the industry that the addition of a prime brings about increased resistance of the bond to weathering or corrosion attack, but this factor was not evaluated in the project. A prime is also known to impart protection from fingerprint contamination to the chemically prepared metal surfaces, although it is not recommended that primed surfaces be subjected to indiscriminate handling.

TABLE 1.

RESULTS OF "FM-47" BONDED PANELS MADE IN "ADHESIVE WEIGHT" AND "CELL SIZE" PROGRAMS, SHOWING EFFECTS OF CELL SIZE, TAPE WEIGHT, AND CORE-PRIME WEIGHT ON PEEL AND TENSILE STRENGTHS.

## Explanation of Failure Coding:

- A = "Adhesion"
- AC = "Adhesion and Cohesion mixed"
- C = "Cohesion"

\* Peels of panels marked with asterisk were believed to have been adversely affected by deterioration of cleaner solution, and were not included in graphs.

Note: Conditions of fabrication are shown at end of table.

TEST NO.	IN.	CELL SIZE	ADHESIVE WEIGHTS					THREE-INCH PEEL					FLATWISE TENSILE					REMARKS		
			TAPE WT.		CORE-PRIME WT.		TOTAL CURE WT.	Actual Avg.	Avg. Specif.	Low Rdg.	Percent Failures					Failure (all between tape & core)				
			INCHES	INCHES	INCHES	INCHES					Facing	Core	A	AC	C	C	AC			
82	.05	.024	.009	.002	.052	22	423	46	--	--	--	--	100	--	0	0	--	C	Failed in sawing .008" foil	
98	.05	.024	.049	.002	.068	46	522	63	--	20	--	80	--	--	235	2670	23	C		
101		.048	0	.002	.091	31	341	65	--	--	--	--	10	90	167	1835	24	AC	.002 "	
44		.049	0	.001	.092	28	304	64	--	--	--	--	100	--	201	2170	63	AC		
60		.048	.009	.001	.093	58	623	59	--	--	--	--	100	--	677	7280	83	AC		
47		.049	.009	approx	.102	53	520	62	--	--	--	--	100	--	518	5080	88	AC		
100		.049	.043	.003	.133	104	783	74	40	--	--	60	--	--	1017	7650	98	C	.002 "	
99		.048	.047	.003	.136	111	816	77	75	--	--	25	--	--	1002	7880	89	C	.002 "	
123			.076	0	.002	.136	90	562	81	--	--	--	2	98	--	727	5350	94	--	.002 "
189			.078	0	.002	.142	84	556	68	--	--	--	--	100	--	770	5420	95	AC,C	
194			.079	0	.002	.138	86	623	68	--	--	--	--	100	--	695	5040	88	C	
195			.077	0	.002	.134	72	538	83	--	--	--	--	100	--	639	4780	90	C,AC	.002 "
174			.081	.008	.001	.148	173	1170	69	--	10	20	25	45	--	--	--	Core		
149*			.078	.014	.001	.147	135*	918*	84	70	28	1	--	1	--	993	6760	92	--	.002 "
192			.075	.019	.002	.156	183	1170	84	2	19	5	42	32	--	1071	6860	86	C	
177			.079	.019	.001	.152	194	1270	82	--	4	15	39	42	--	1214	7990	93	C	.002 "
171			.082	.020	.002	.156	203	1300	73	--	15	15	40	30	--	1187	7610	97	C	.002 "
184			.079	.030	.002	.163	189	1150	57	--	50	12	10	28	--	1130	6950	87	C	.002 "
125*			.077	.031	.002	.159	109*	686*	82	95	5	--	--	--	--	1187	7460	88	--	.002 "
126*			.080	.031	.002	.164	139*	847*	76	75	24	1	--	--	--	1154	6850	97	C	.002 "
193			.076	.031	.001	.159	188	1180	79	3	87	5	1	4	--	1221	7680	88	C	.002 "
199			.075	.035	.002	.162	175	1080	86	--	83	13	2	2	--	1372	8490	97	C	.002 "
155			.078	.048	.002	.179	179	1000	90	3	15	28	50	4	--	--	--	Core		
147			.078	.048	.001	.177	193	1090	85	--	25	70	3	--	--	--	--	Core		
148*			.081	.049	.003	.178	152*	854*	71	35	20	25	18	2	--	--	--	Co.	*	
128*			.081	.050	.002	.187	120*	642*	83	87	11	1	1	--	--	1327	7090	98	C	.002 "
127*			.078	.051	.002	.178	111*	624*	76	92	6	1	1	--	--	1382	7760	94	C	.002 "

TABLE 1 (continued)

TEST NO.	CELL SIZE	D. (continued)	ADSORBENT WEIGHTS						TENSILE-TEST PWL						FLATWISE-TENSILE						REMARKS				
			TAPE WT.			TOTAL			Actual Avg.	Avg. Speci- fic	Low Mdg.	Percent Failures						Actual Avg.	Avg. Speci- fic	Low Mdg.	Failure (all between tape & core)				
			NORMAL	ADHESIVE	(1 side)	(2 sides)	(2 sides)	(1 side)				TEST	PER. #/IN. <sup>2</sup>	PWLT #/IN. <sup>2</sup>	Avg.	Facing	Core	C	S	AG	A				
106			.085	0	.002	.146		121	829	74	--	--	--	25	85	--	840	3750	95	C	.002 fail				
114			.087	0	.003	.153		114	765	75	--	--	--	5	95	--	762	3110	89	C	.002 "				
196			.085	0	.002	.149		120	805	83	--	--	--	5	95	--	849	3700	93	C					
204			.085	.008	.001	.156		193	1230	82	3	59	3	5	30	--	1264	7460	97	C	.002 "				
113			.086	.015	.003	.163		208	1260	82	--	7	34	34	23	--	1055	6390	98	C	.002 "				
107			.088	.016	.002	.163		200	1230	79	9	61	3	7	20	--	1159	7120	91	C	.002 "				
205*			.084	.026	.001	.170		168*	990*	67	18	82	2	3	1	--	1271	7490	96	C	*.002 "				
157			.084	.043	.002	.183		187	1620	86	1	81	6	7	3	--	----	----	--	Core					
104			.098	0	.002	.161		207	1280	78	11	19	13	5	1	51	991	6140	98	75% C 25% AC	.002 "				
118			.100	0	.002	.170		199	1170	69	--	9	16	5	70	--	1010	5940	94	--	.002 "				
200*			.094	.002	.002	.168		159*	947*	77	--	29	--	4	67	--	1143	8650	98	C	*.002 "				
191*			.098	.008	.002	.180		179*	999*	88	--	97	1	1	1	--	----	----	--	Core	"				
105			.096	.015	.002	.173		237	1370	80	1	54	42	1	2	--	1169	6760	97	C	.002 "				
180			.100	.028	.002	.192		230	1200	85	5	84	10	1	--	--	1357	7060	99	--	.002 "				
121			.098	.029	.003	.190		227	1195	83	2	50	47	1	--	--	1330	7000	98	--	.002 "				
202*			.097	.040	.002	.202		201*	999*	88	2	93	1	2	2	--	1356	6980	93	C	*.002 "				
156			.077	0	.003	.135		65	488	77	--	--	--	100	--	--	409	3030	67	AC					
167			.081	.003	.002	.145		106	731	71	--	--	--	7	93	--	726	5000	91	C					
131			.078	.016	.002	.148		157	1060	78	10	44	6	30	10	--	790	5330	97	C					
137			.080	.017	.002	.151		151	1000	74	--	--	11	71	18	--	745	4930	85	--					
179			.079	.037	.002	.177		153	865	74	--	--	--	42	58	--	879	4970	91	C					
153*			.080	.047	.001	.179		111*	620*	81	92	8	--	--	--	--	956	5340	98	--	*				
136			.079	.051	.002	.183		176	962	72	10	72	15	3	--	--	915	5000	92	--					
134			.079	.054	.002	.190		188	989	67	4	5	49	35	7	--	897	4720	95	--					

(Continued)

TABLE 1 (continued)

SAMPLE	CBL. SIZE	IN.	ADHESIVE WEIGHTS					TENSILE-INCH PEEL						FLATWISE TENSILE						REMARKS		
			TAPE WT.		ADHESIVE		TOTAL CROWN WEIGHT IN.²	Actual Avg.	Avg. Speci- fic	Low Rdg.	Percent Failures						Actual Avg.	Avg. Speci- fic	Low Rdg.	Failure (all between tape & core)		
			INCHES	POUNDS	INCHES	POUNDS					Psi. Inch-#	Psi. #/Pt²	Psi. Avg.	Facing	Core	A	AC	C	G	AC	A	
43			.049	0	.001	.092	28	304	82	--	--	--	--	100	--	117	1270	34	AC			
102			.049	0	.003	.090	21	233	57	--	--	--	--	5	95	0	0	--	C			
103		0	.048	.009	.002	.098	45	459	72	--	--	--	--	95	5	--	395	3930	74	C		
81			.048	approx	.001	.092	45	489	80	--	--	--	--	100	--	352	3830	90	AC			
97			.048	.033	.003	.117	94	804	73	39	44	--	17	--	--	669	5720	94	C			
96			.048	.034	.003	.118	73	619	79	17	63	--	20	--	--	651	5520	92	AC			
88			.071	0	.002	.131	42	321	74	--	--	--	--	100	--	331	2930	80	AC			
86		0	.072	0	.001	.131	55	420	76	--	--	--	--	100	--	372	2840	80	AC			
173			.031	.004	.001	.147	80	544	58	--	--	--	--	36	64	--	570	3880	94	AC		
168			.079	.004	.001	.138	76	551	56	--	--	--	--	100	--	541	4920	92	C			
185			.079	.011	.002	.139	91	655	73	--	--	--	--	24	76	--	639	4600	97	C		
154*			.077	.083	.001	.151	98*	649*	63	33	49	--	3	15	--	651	4310	94	--	*		
129			.079	.027	.001	.157	143	910	73	--	2	7	85	6	--	665	4240	94	C			
138		0.079	.078	.026	.002	.158	134	848	73	--	1	10	73	16	--	635	4020	96	--			
143			.079	.030	.001	.161	134	832	68	1	10	14	71	4	--	639	3970	91	--			
139			.078	.035	.002	.165	126	763	79	--	1	1	79	19	--	645	3910	96	--			
130*			.080	.027	.003	.171	118*	690*	85	65	24	3	5	2	--	757	4430	99	C	*		
172			.078	.04	.002	.183	157	657	66	--	8	--	60	32	--	792	4330	94	C			
109			.089	0	.003	.152	73	480	70	--	--	--	--	100	--	443	2920	85	AC			
115			.086	0	.003	.153	63	412	73	--	--	--	--	100	--	421	2750	71	AC			
108			.086	.007	.003	.153	110	720	66	54	15	--	--	31	--	649	4240	96	C			
117			.086	.007	.002	.157	120	765	68	--	--	10	64	26	--	663	4230	96	--			
203			.085	.035	.003	.181	158	873	80	7	70	4	--	19	--	758	4400	94	C			
122			.085	.037	.002	.178	189	1060	72	2	34	40	19	5	--	815	4580	97	--			

(Continued)

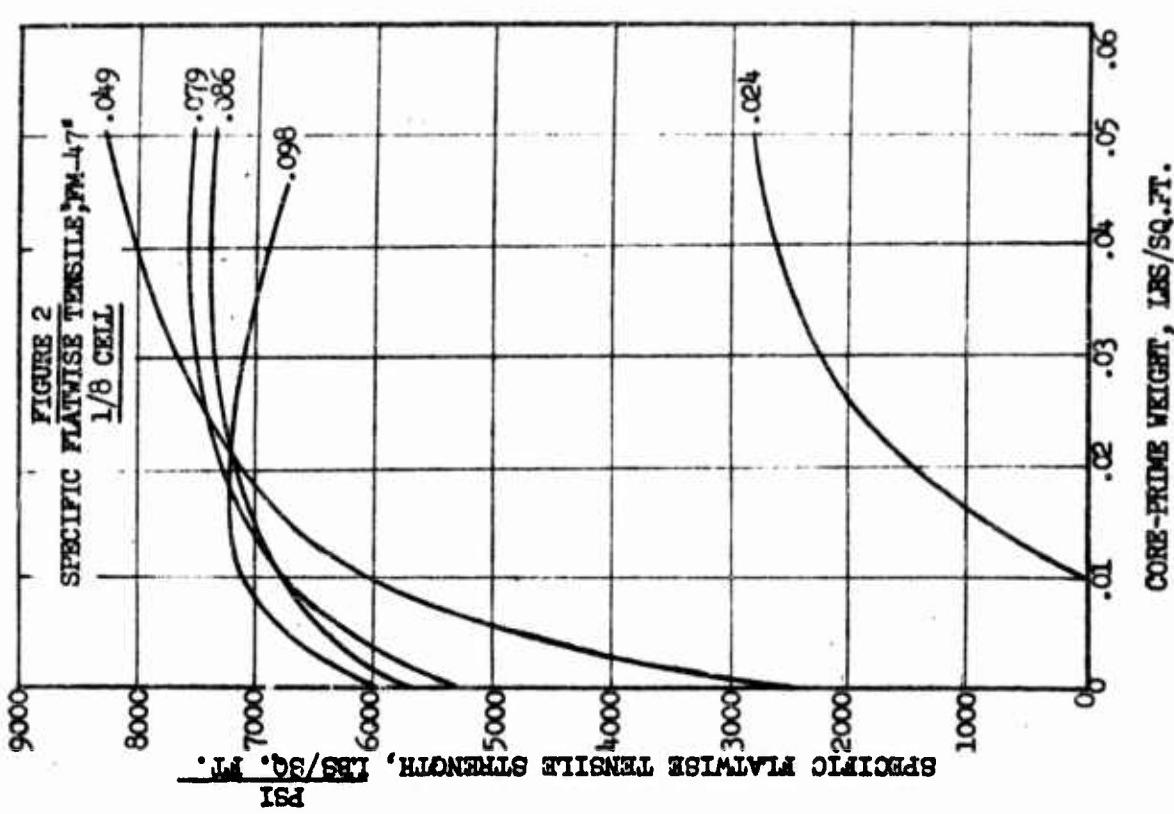
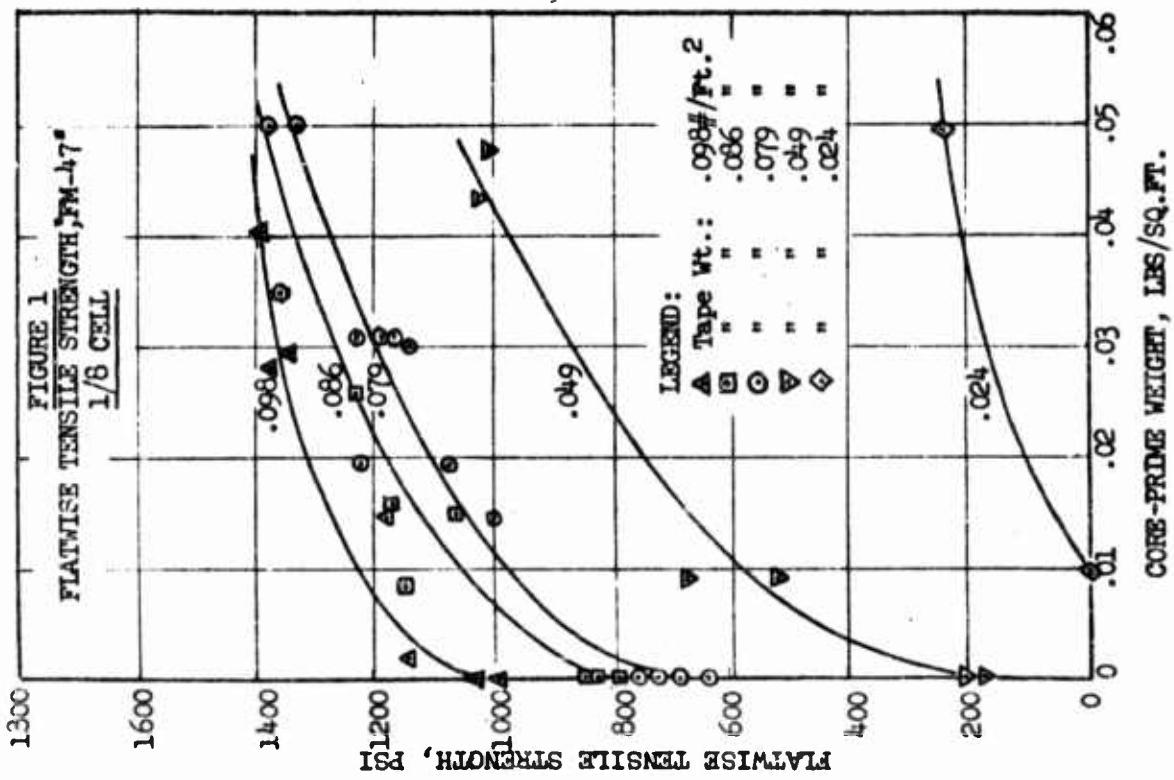
TABLE 1 (continued)

PANEL NO.	CORE SIZE - In.	ADHESIVE WEIGHTS						THREE-INCH PEEL						FLATWISE TENSILE						REMARKS
		TAPE WT.		CORE WT.		TOTAL WT.		Actual CURE Time	Avg. Speci- fic	Low Mag.	Percent Failures					Actual Avg.	Avg. Speci- fic	Low Mag.	Failure (all between tape & core)	
		REGULAR	ACTUAL	REGULAR	ACTUAL	CORE	TOTAL WT.				Inches of Peel Avg.	Psi. of Avg.	Face	Core	A	AC	C	C	AC	A
110	1/2	.100	0	.002	.175	121	691	56	19	13	3	2	65	--	580	3310	92	C		
186	1/2	.095	.004	.002	.170	148	871	66	--	6	4	46	44	--	793	4660	96	C		
111	1/2	.093	.006	.002	.167	149	892	86	--	2	10	77	11	--	723	4330	95	C		
188	1/2	.099	.027	.001	.193	167	865	76	--	74	5	15	6	--	835	4330	95	C		
119	1/2	.097	.032	.002	.192	180	937	80	2	--	78	12	8	--	805	4190	96	--		
190	1/2	.099	.036	.002	.203	171	843	87	--	54	5	8	33	--	803	3950	96	C		
201*	1/2	.097	.055	.002	.217	167*	770*	75	--	65	7	25	3	--	901	4150	98	C	*	
170	1/2	.079	.004	.002	.143	67	470	69	--	--	100	--	--	--	340	2380	82	AC		
141	1/2	.079	.008	.002	.149	63	423	71	1	--	79	20	--	--	394	2650	88	--		
135	1/2	.077	.011	.001	.148	69	466	49	--	--	92	8	--	--	380	2570	84	--		
180	1/2	.079	.017	.002	.154	92	600	83	--	--	37	63	--	--	439	2860	91	C		
142	1/2	.080	.034	.002	.168	93	554	75	6	5	--	70	19	--	454	2710	96	--		
140	1/2	.082	.052	.002	.170	108	635	76	10	9	27	35	19	--	450	2650	93	--		
169	1/2	.079	.054	.001	.180	115	640	61	--	8	--	60	32	--	542	3000	90	C		

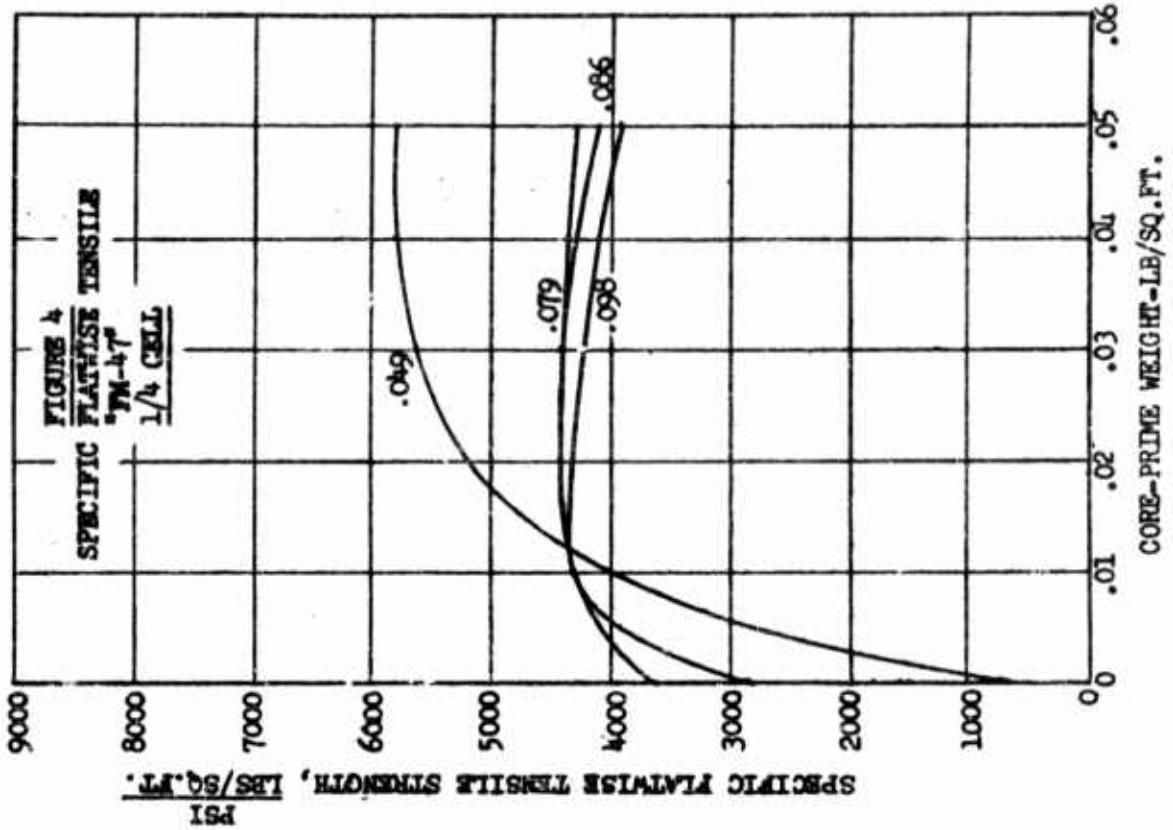
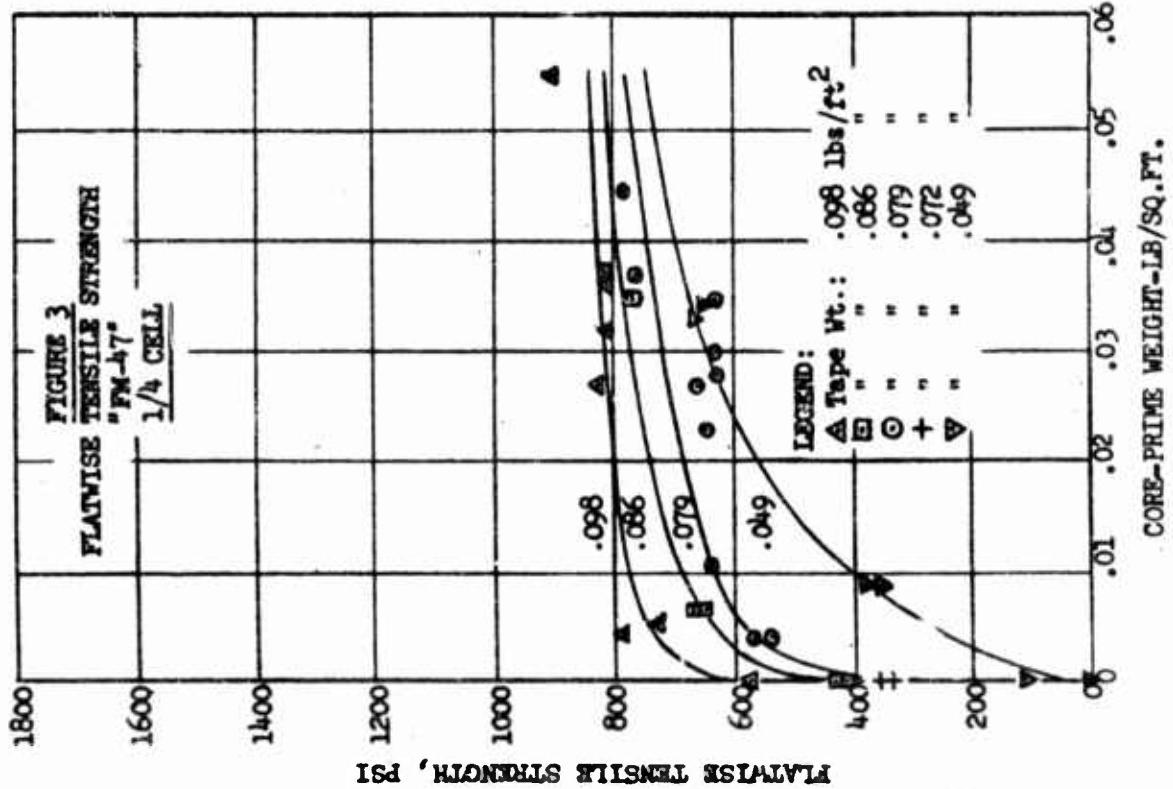
\* Peels of panels marked with asterisk were believed to have been adversely affected by deterioration of cleaner solution, and were not included in graphs.

#### Conditions of Fabrication:

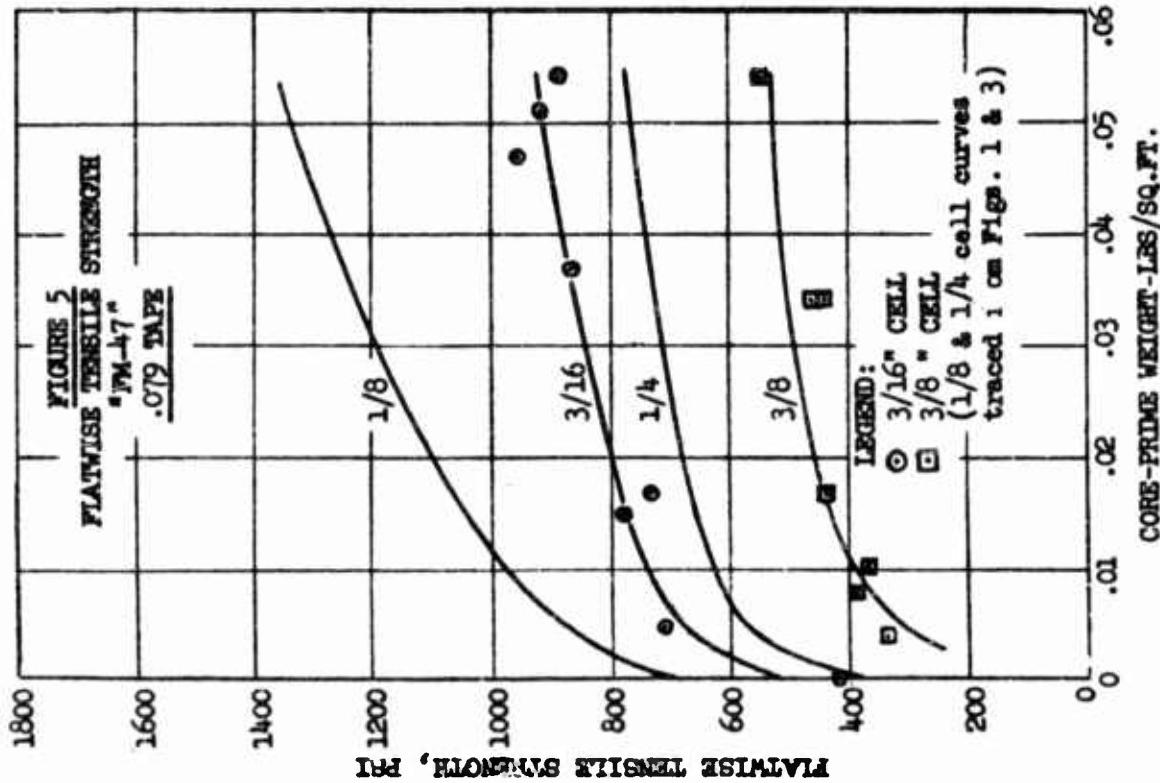
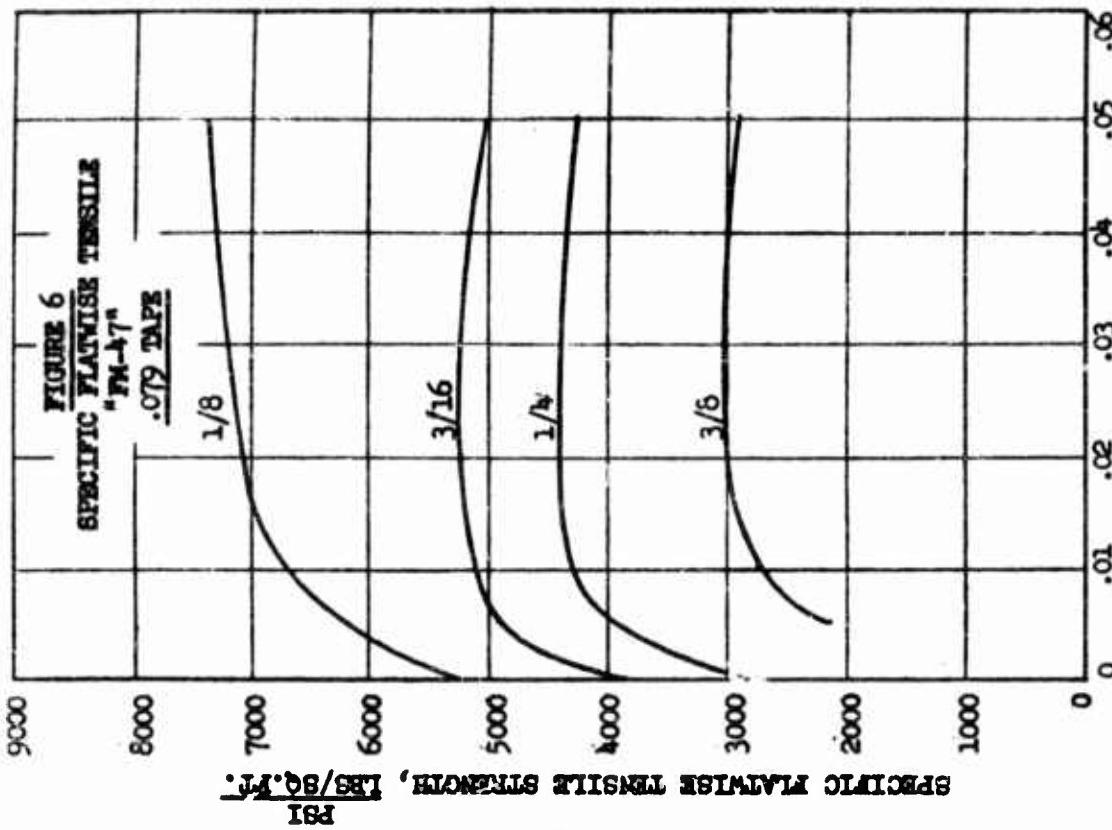
- Facings: Alclad 248-T3, 0.016 inches thick.
- Core: Al 1/8-0.0015, Al 1/8-0.002, Al 3/16-0.002, Al 1/4-0.003, Al 3/8-0.003, all "expanded-type", cut 0.625 inches thick.
- Cleaning: Facings degreased 10 minutes in hot alkaline cleaner, immersed 5 minutes in sulfuric acid-sodium dichromate solution at 140°F, hot spray rinse (solution concentrations were known to have varied significantly throughout the program). Core material was not cleaned. Storage and exposure conditions were not maintained constant throughout the program.
- Priming: Facings were brush-primed with dilute solutions of TM-47, force-dried with hot-air gun. Core was primed in roller coater and air dried (depth was 0.035 inches, approx., but was not held constant). (Prime and tape weights shown in table are uncured.)
- Cure: 5 minutes at 3 - 4 psi, 60 minutes at 35 psi, 345°F.
- Specimens: 3 to 4 each, peel and tensile.



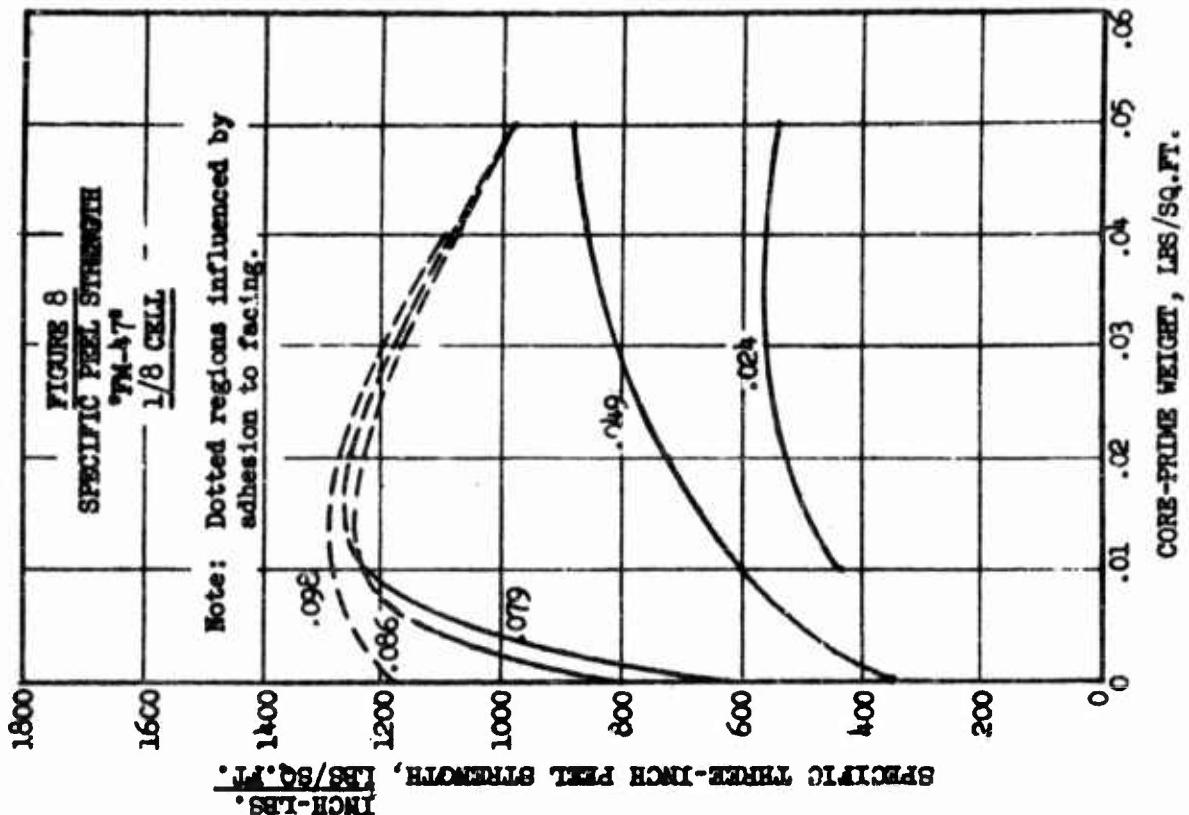
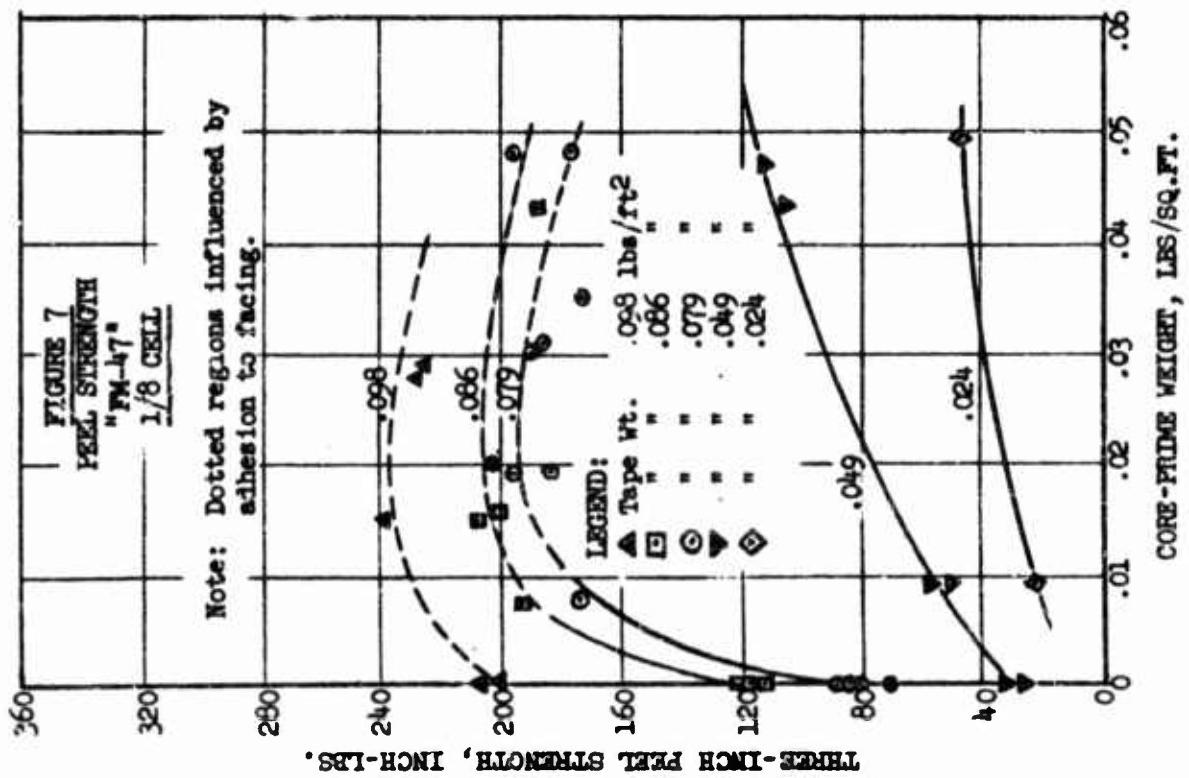
FIGURES 1 & 2: Actual & specific FLATWISE TENSILE STRENGTHS, vs. core-prime weight at various "FM-4-7" tape weights; 1/8" CELL SIZE (from Table 1). Pacings: Alceld 243-F3, .016" thick, primed to .002 lbs/sq.ft. All weights are dried, uncured. Core-prime weights include both sides.



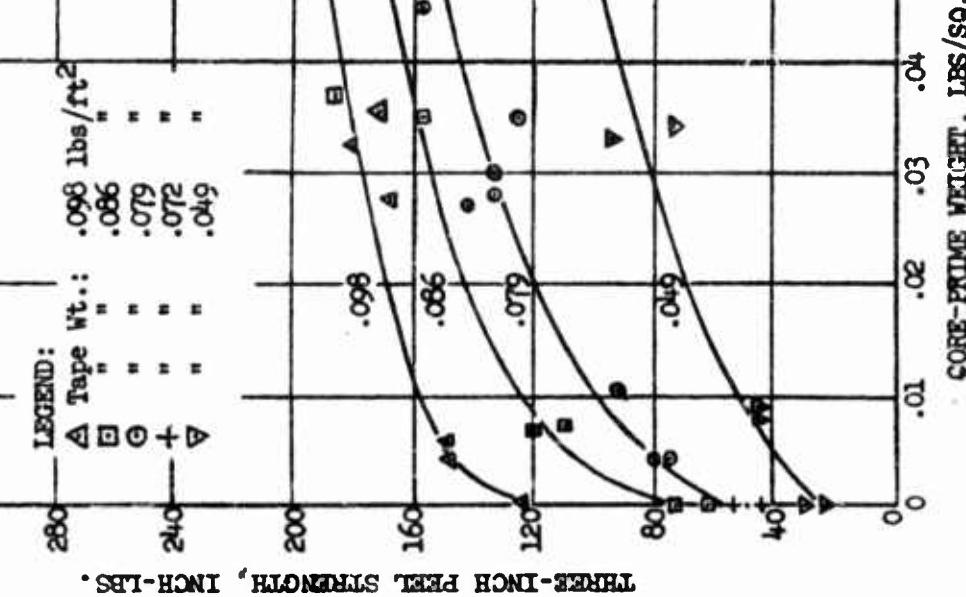
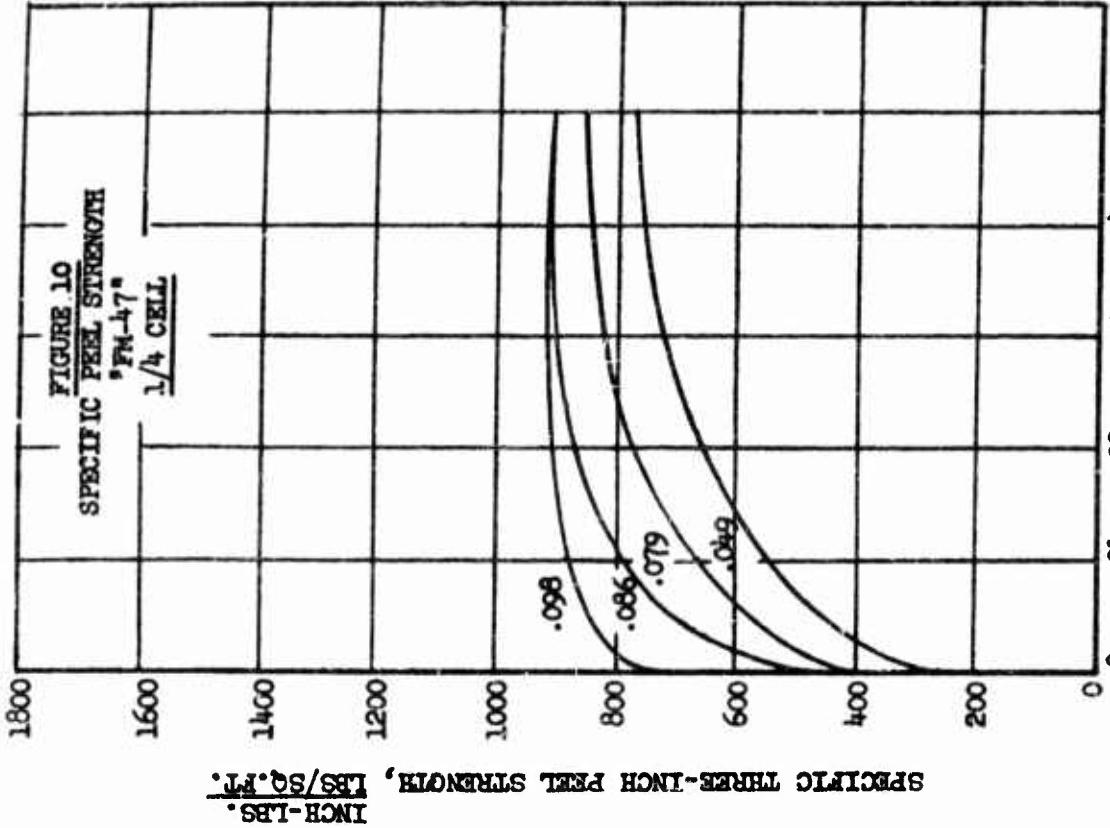
FIGURES 3 & 4: Actual and specific FLATWISE TENSILE STRENGTHS vs. core-prime weight at various "FM-47" tape weights;  $\frac{1}{4}$ " CELL SIZE (from Table 1). Facings: Alclad 24S-T3, ".016" thick, primed to .002 lb/sq.ft. All weights are dried, uncured. Core-prime weights include both sides.



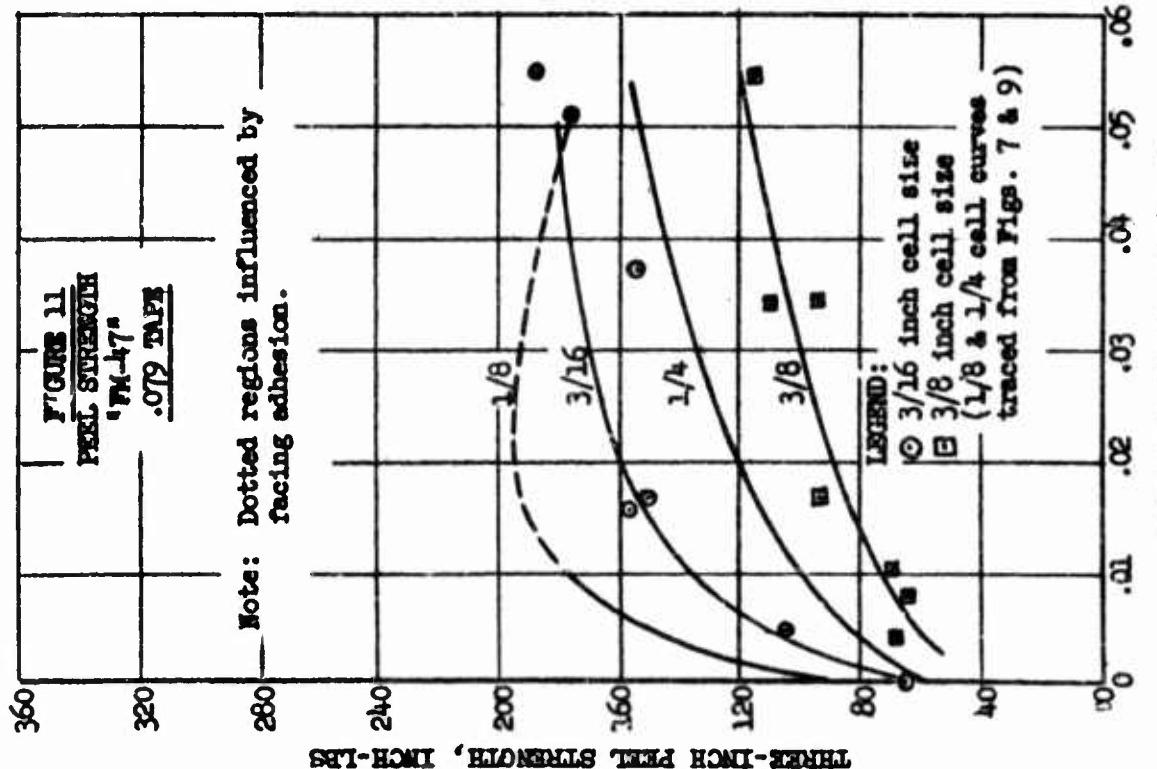
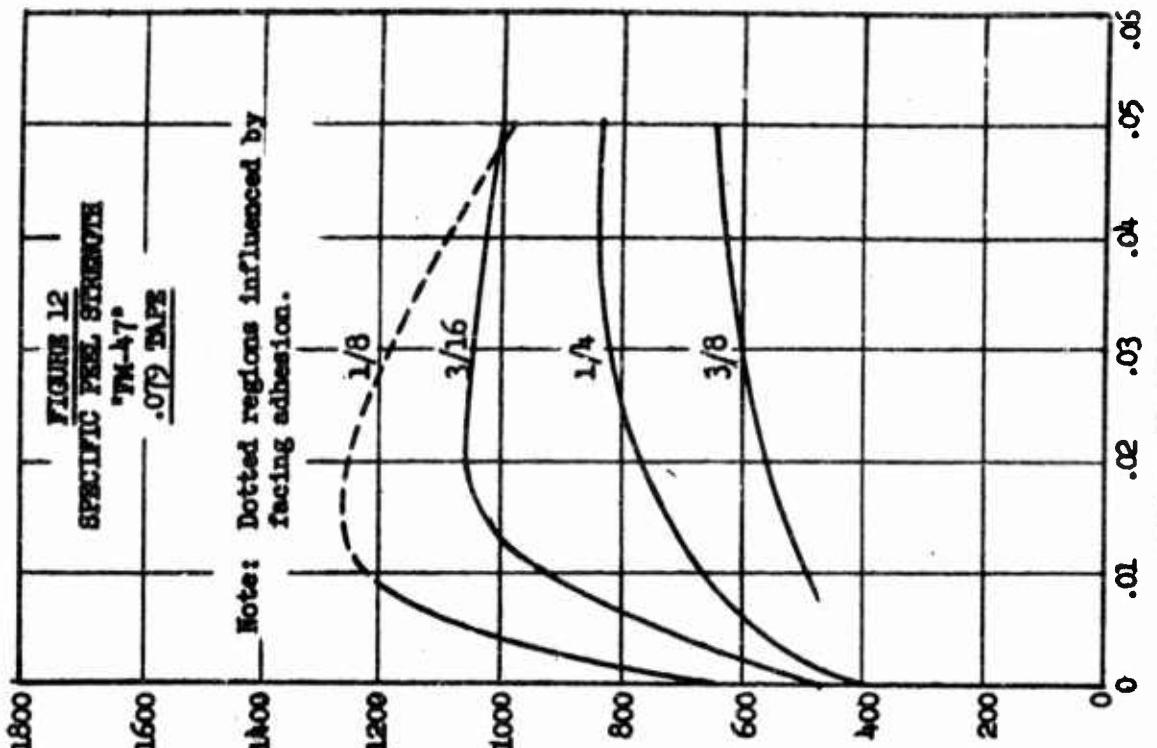
**FIGURES 5 & 6: Actual and specific FLATWISE TENSILE STRENGTHS vs. core-prime weight for various CELL SIZES (from Table 1). Facings: Alciad 24S-T3, .016" thick, primed to .002 lbs/sq.ft. All weights are dried, uncured. Core-prime weights include both sides.**



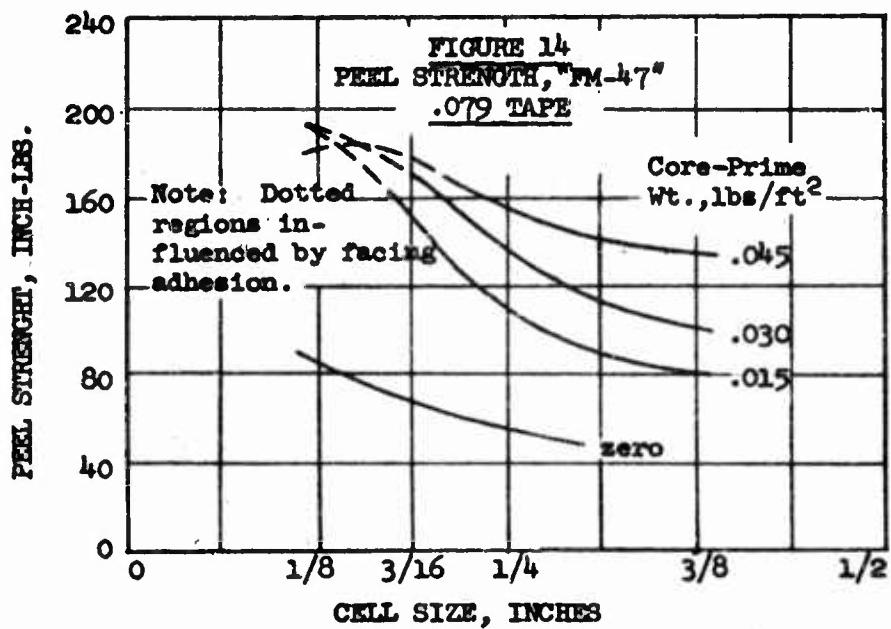
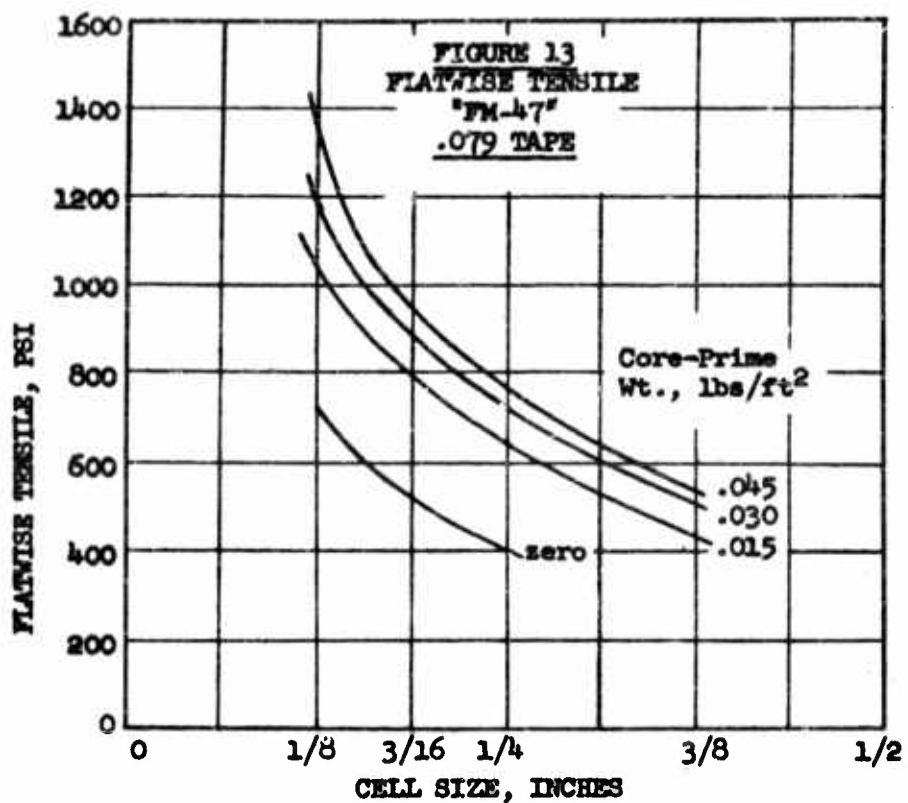
FIGURES 7 & 8: Actual and specific three-inch PEEL STRENGTHS, vs. core-prime weight, at various "TM-47" tape weights; 1/8" CELL SIZE (from Table 1). Facings: Alclad 24S-T3, .016" thick, primed to .002 lbs/sq.ft. All weights are dried, uncured. Core-prime weights include both sides.



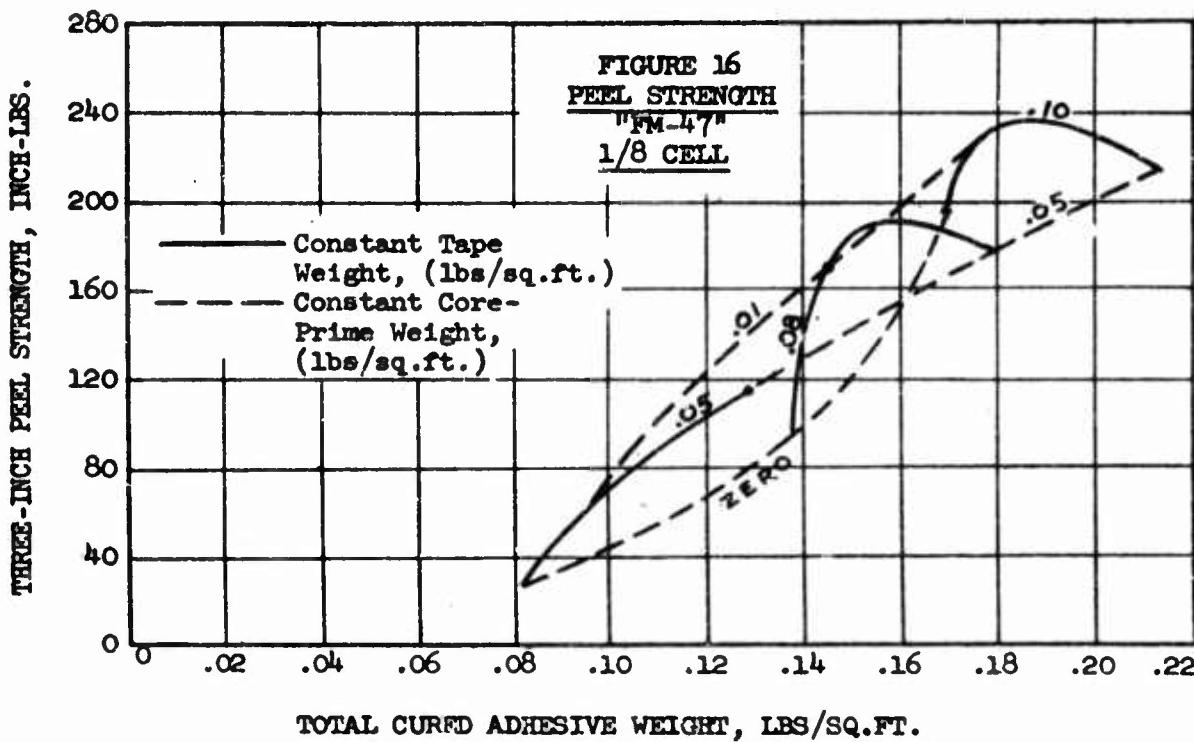
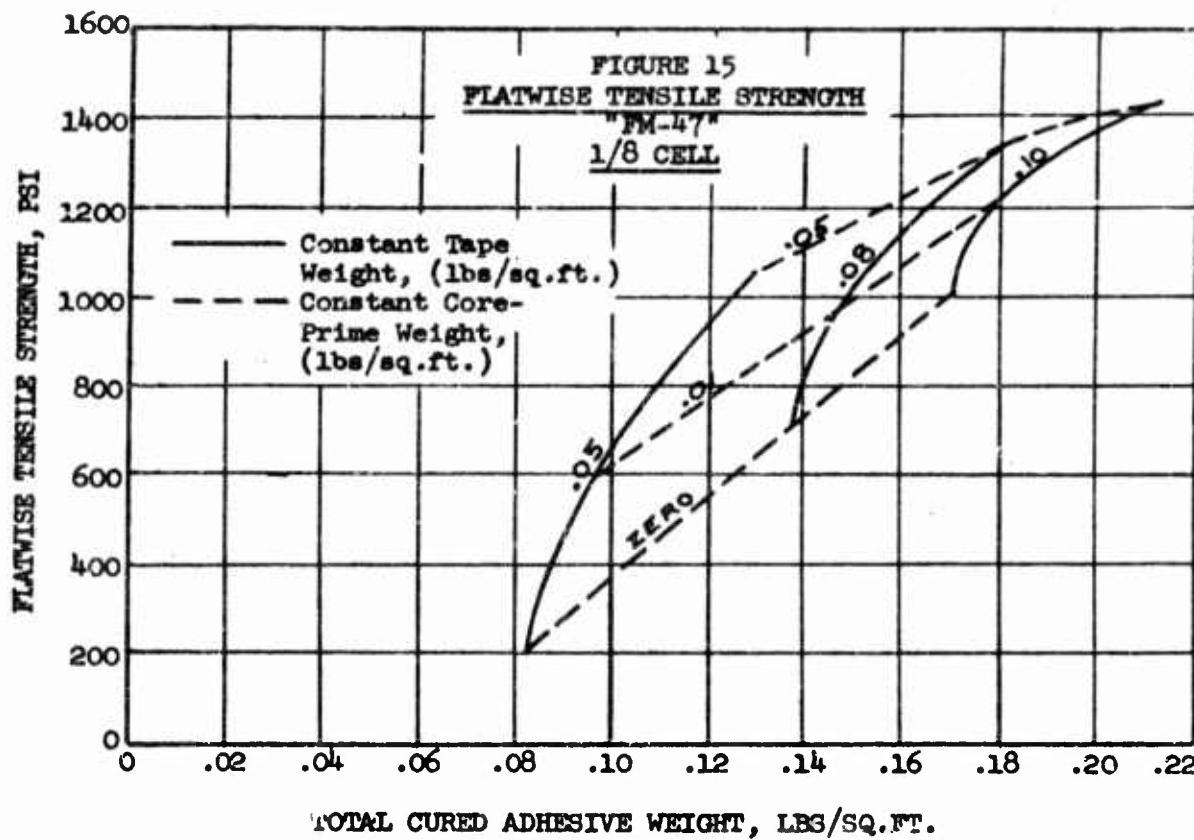
FIGURES 9 & 10: Actual and specific THREE-INCH PEEL STRENGTHS, vs. core-prime weight at various "FM-47" tape weights; 1/4" CELL SIZE (from Table 1). Facings: Alcelad 24S-T3, .016" thick, primed to .002 lbs/sq.ft. All weights are dried, uncured. Core-prime weights include both sides.



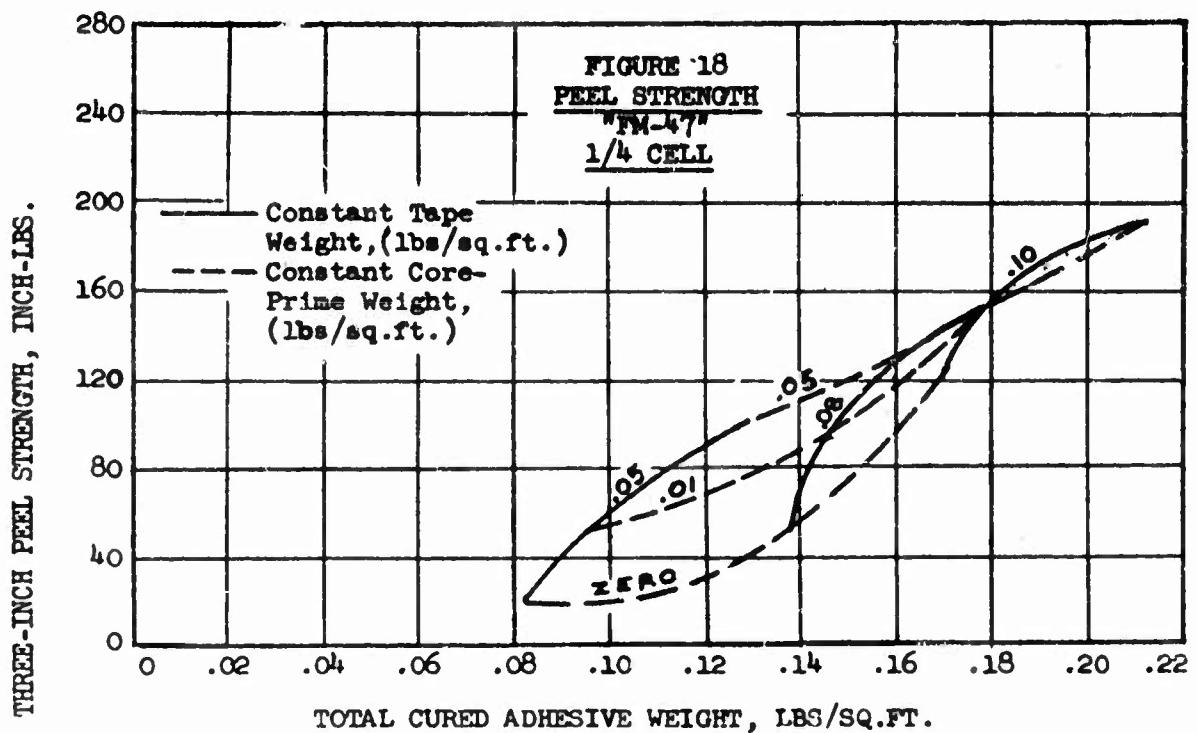
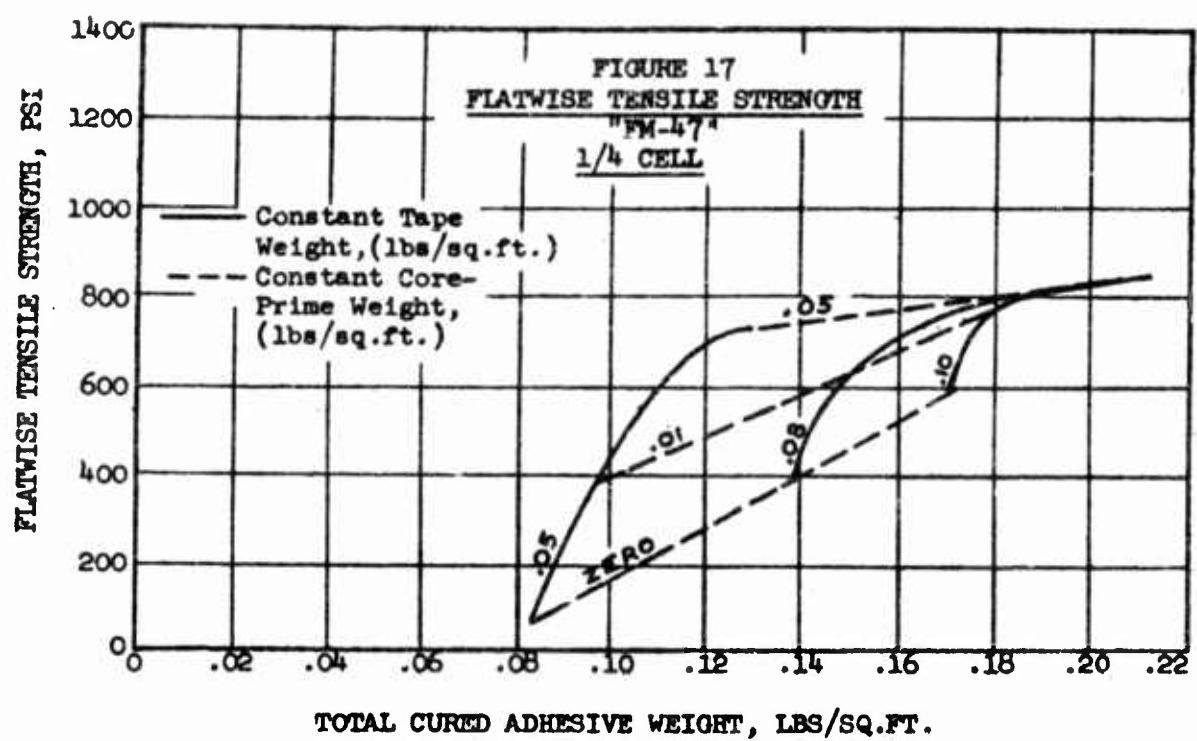
FIGURES 11 & 12: Actual and specific three-inch PEEL STRENGTHS vs. core-prime weight for various CELL SIZES. Tape wt.: .072 lbs/sq.ft. (from Table 1). Facings: Alcold 24S-T3, .016" thick, primed to .002 lbs/sq.ft. All weights are dried, uncured. Core-prime weights include both sides.



FIGURES 13 & 14: FLATWISE TENSILE & PEEL STRENGTHS VS. CELL SIZE at various "FM-47" core-prime weights, .079 lbs/sq.ft. tape weight (from Figs. 1,3,6 & 7). Facings: Alclad 248-T3, primed to 0.002 lbs/sq.ft. All weights are dried, uncured. Core-prime weights include both sides.



FIGURES 15 & 16: FLATWISE TENSILE AND PEEL STRENGTHS vs. TOTAL CURED WEIGHT OF "FM-47" 1/8 CELL. (From Figs. 1 & 7). Facing: Alclad 248-T3, 0.016" thick, primed to 0.002 lbs/sq.ft. All weights, except total weight, are dried, uncured. Core-prime weights include both sides.



FIGURES 17 & 18: FLATWISE TENSILE AND PEEL STRENGTHS vs. TOTAL CURED WEIGHT OF "FM-47", 1/4 CELL. (From Figs. 3 & 9). Facings: Alclad 248-T3, 0.016" thick, primed to 0.002 lbs/sq.ft. All weights, except total weight, are dried, uncured. Core-prime weights include both sides.

**TABLE 2**  
**EFFECT OF CORE-PRIME DEPTH ON BOND EFFICIENCY**

**Explanation of Failure Coding:**

A - "Adhesion"  
 AC - "Adhesion and Cohesion mixed"  
 C - "Cohesion"

**NOTE: All flatwise tensiles failed  
 in cohesion at core.**

Panel Number	Cell Size	One-Eighth Inch	One-Quarter Inch	THREE INCH PEEL												FLATWISE TENSILE												
				ADHESIVE WEIGHTS			Avg. Actual			Avg. Specific			Percent Failures			FACING			CORE			Ave. Actual						
				Tape Weight #/Sq.Ft.	Core-Prime #/Sq.Ft.	Priming-Prime #/Sq.Ft.	Core-Prime (2 Sides) #/Sq.Ft.	Priming-Prime (2 Sides) #/Sq.Ft.	Tape Weight (1 Side) #/Sq.Ft.	Total Gured Wt. (2 Sides) #/Sq.Ft.	Inch-lbs. Inch-lbs.	Inch-lbs. Inch-lbs.	Inch-lbs. Inch-lbs.	A	AC	C	C	AC	A	PSI	PSI	PSI	PSI	PSI				
274	.025	.015	.015	.015	.015	.015	.015	.015	.015	.015	.010	.020	.120	.002	.006	.006	.002	.014	.013	1020	--	--	921	938				
269	.060	.020	.010	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.002	.006	.006	.002	.014	.013	1160	1090	10	15	40	35	946		
268	.060	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.002	.006	.006	.002	.014	.013	123	138	900	2	3	44	51	916	
273	.060	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.002	.006	.006	.002	.014	.013	123	1080	3	12	7	54	907		
272	.060	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.002	.006	.006	.002	.014	.013	123	77	630	--	--	5	95	923	
270	.060	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.002	.006	.006	.002	.014	.013	123	71	575	602	--	2	25	73	576
267	.060	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.015	.002	.006	.006	.002	.014	.013	123	80	605	565	--	1	--	12	88
																				525	525	525	525	525	525	525	525	525
																				586	586	586	586	586	586	586	586	586
																				4380	4380	4380	4380	4380	4380	4380	4380	4380
																				4160	4160	4160	4160	4160	4160	4160	4160	4160

TABLE 3

EFFECT OF "FM-47" FACING-PRIME WEIGHT ON SANDWICH BOND STRENGTH  
 (Lightly primed areas adjacent to either unprimed or heavily primed areas in each 10 inch x 18 inch panel. Peels run across line of demarcation; tensiles pulled from each side of line of demarcation.  
 "FM-47" tape weight, prime weight, and cell size variable.)

Explanation of Failure Coding:  
 A = "Adhesion"  
 AC = "Adhesion and cohesion mixed"  
 C = "Cohesion"

PANEL NO.	CELL SIZE - In.	PRIME COMPOSITION	ADHESIVE WEIGHTS				THREE-INCH PEEL										FLATWISE TENSILE						
			TAPE WEIGHT (1 side) # Sq.Ft.	CONC-PRIME (2 sides) # Sq.Ft.	FACED-PRIME (1 side) # Sq.Ft.	TOTAL CURSED # Sq.Ft.	Actual Avg.	Specific Peel				Percent Failures						Actual Avg.	Specific Tensile				Failures all Core to Tape
								Avg.	In. #	In. #	#/ft <sup>2</sup>	None Light	Heavy Light	Peeling	Core	Psi	Avg.	In. #	#/ft <sup>2</sup>	None Light	Heavy Light		
189			.078	0	.002	.142	84	590	609	1.03	--	--	--	--	100	--	--	770*	5420	6940	.91	--	AC,C AC,C
276			.067	.021	.002	.142	171	1200	965	.80	--	2	23	--	61	14	--	1165	8200	8200	1.00	--	C C
204			.085	.008	.001	.156	193	1240	1100	.89	--	2	47	3	5	43	--	1164*	7470	7900	1.07	--	C C
205			.084	.026	.001	.170	168	990	875	.88	--	12	80	2	3	3	--	1271*	7480	7770	1.03	--	C C
202			.097	.040	.002	.197	201	1020	770	.75	--	2	73	1	2	2	--	1396*	7080	7480	1.05	--	C C
279	ONE-QUARTER	None vs. Light	.072	.006	.002	.132	153	1160	1100	--	.95	--	16	44	37	3	--	908	6850	7500	--	1.09	C C
708			.076	0	.002	.134	125	935	895	--	.96	--	--	10	80	10	--	916	6830	6250	--	.92	C C
707			.069	.020	.002	.142	193	1370	1270	--	.93	--	5	--	5	90	--	1285	9050	7300	--	.81	C C
184			.079	.030	.002	.163	189	1160	1180	--	1.02	--	50	12	10	28	--	1130*	6940	7200	--	1.04	C C
191		Light vs. Heavy	.102	.008	.002	.180	179	995	1000	--	1.01	--	97	1	1	1	--	--	--	--	--	--	{Core} (Core)
277		None vs. Light	.066	.004	.002	.118	82	695	720	1.03	--	4	--	--	15	85	--	513	4350	4600	1.05	--	C C
278			.070	.021	.003	.143	125	880	965	1.09	--	11	49	--	14	78	--	523	5050	5000	.99	--	C C
188			.099	.027	.002	.196	167	850	733	.86	--	1	96	3	--	--	--	835*	4260	4120	.96	--	C C
201			.097	.055	.002	.213	167	763	618	.79	--	1	65	7	25	3	--	901*	4230	4220	1.00	--	C C
185	ONE-QUARTER	Light vs. Heavy	.079	.011	.002	.139	91	650	612	--	.94	--	--	--	24	76	--	646*	4650	4300	--	.92	C C
280			.067	.029	.002	.139	117	840	800	--	.95	--	--	5	45	50	--	641	4600	4500	--	.98	C C
203			.085	.035	.003	.176	158	900	983	--	1.03	3	70	--	4	19	--	758*	4310	4000	--	.93	C C

\* Average of three specimens only. Other tensile averages are based on five specimens.

## SECTION I, Continued

### B - FACING PRIME VARIABLES:

The effect of weight of facing prime in a typical sandwich bond was discussed in Part A of this section. Studies of several other facing prime variables conducted on "three-tape" panels (peel strength at adhesive-to-facing interface only) are presented in Tables 4 through 6 at the end of this discussion. A study of the effect of dye in the priming solution is shown in Table 4. The purpose of the evaluation was to determine if this change in fabrication procedure had caused any loss of control of bond strength results obtained in the project. In the same evaluation, "FM-45" was compared with "FM-47" as a facing prime, in the belief that it might give somewhat superior adhesion to the facing. From the limited results shown in Table 4, there does not appear to be any advantage in using "FM-47" tape with a prime of "FM-45", and there does not appear to be any obvious structural disadvantage in dyeing the priming solution. The experiment cannot be construed to imply that either formulation is superior as a sandwich adhesive.

Since a strong color is very desirable in a prime (particularly a facing prime) to facilitate inspection, the contractor recommends that adhesive manufacturers consider the possibility of qualifying their formulations with a dye already in solution. The dye intensity should be capable of rendering a strong coloration to a coating weighing 0.002 lbs/sq.ft., (dried) on an aluminum surface. The particular dye used here ("OIL RED 'O'", manufactured by the National Aniline Co.) is not readily soluble in the thinner and was not thoroughly evaluated to determine if any detrimental effects might result from its use. Dyes which are considered for use in metal adhesives should be evaluated to determine their possible effects on corrosion resistance.

A third variable, explored in Table 4, was the effect of precure. The conditions of fabrication were the same as in the "FM-47" undyed" panels except that the primed facings were given an oven cure for 35 minutes at 325°F, whereas the primed facings in the other groups were force-dried only. The average peel strength of 155 inch-lbs. obtained from the three panels was lower than in any of the other groups. It was tentatively concluded that precuring the facing prime tended to lower peel strength but it was decided to perform a more thorough study.

A further study of the effect of precure, and of storage before and after precure is presented in Table 5. Precuring time at 300°F was varied from zero to sixty minutes on two groups of panels, which were then stored for three days and seventeen days, respectively. In both groups, the peel strengths struck a minimum at an oven time of approximately two minutes. (The minimum was still within the range of "optimum" peel values observed throughout the project.) Peel strengths again came up to the original "no-precure" levels after five or ten minutes. A definite accompanying trend can be seen in the characteristics of the failures. Apparently, the prime's strength in adhesion increased in comparison to its strength in cohesion, when precure time was extended.

I - B, Continued

The extended storage after precure reduced peel strength by approximately six percent. Panels 410 and 411, which received a long storage before a five-minute precure, exhibited a peel strength loss of only two percent as a result of the storage. These results contradicted the tentative conclusion that long precures downgrade peel strength.

The last evaluation in the series, presented in Table 6, dealt with precuring and finger-handling of the prime as parameters, and also determined the protective effect of a paper-backed polyethylene "interleaf", laminated to the prime. (The evaluation of the interleaf was in conjunction with an unsuccessful attempt to develop a method for continuously laminating paper-backed polyethylene to the facing prime in a machine used for cleaning and priming coil stock.) As in the case of the "Facing Prime Weight" panels (Section I, Part A - 3), two test conditions were incorporated in each panel, separated by a line of demarcation. Paper-backed polyethylene was laminated under heat and pressure over one half of the surface of each primed facing. The unprotected portions of four of the primed facings were covered profusely with fingerprints by six laboratory and office workers. (It should be noted that these persons' hands were relatively clean.) Another four facings having protective coverings laminated to half of their primed surfaces, received no fingerprint contamination whatsoever. The paper-backed polyethylene was then stripped from all eight of the test facings. Eight "three-tape" panels incorporating these facings were bonded and tested in peel.

The peeling torque representing the conditions on each side of the line of demarcation have been presented in separate columns in Table 6. In every case, the peel strength in the protected area was higher than that in the unprotected area. Fingerprints on the surfaces lowered peel strength only about two percent below the values observed on the unprotected areas which were not handled. A third trend observable in Table 6 is an upgrading of peel strength by a short precure, contrary to the results of the previous evaluation.

The three evaluations of the effect of facing precure on peel strength (Tables 4, 5, and 6) gave generally contradictory results each time, but the magnitudes of the upward and downward gradients in the latter two evaluations were small, while the large drop shown in the first evaluation was probably a manifestation of other uncontrolled test conditions. The following general conclusions can be drawn:

1. The precuring performed on the facing prime may either increase or decrease peel strength, but the variation is small.
2. An increase in the duration of the precure of the facing prime causes the strength of the bond in adhesion to increase with respect to its strength in cohesion.

I - B, Continued

3. Fingerprints applied to the primed surface of the facing by persons with relatively clean hands, did not bring about large reductions in peel strength. (It is not recommended that primed surfaces be handled with the bare fingers.)
4. A film of polyethylene, laminated under heat and pressure to the facing prime coat appears to afford positive protection to the surface during storage and handling. Its use would not ordinarily be justified, however.

Other variables in connection with the facing prime, which do not directly influence bond strength, are discussed in Section II, Parts B and D, of this report.

**TABLE 4**  
EFFECTS OF SEVERAL FACING-PRIMING VARIABLES ON PEEL STRENGTH

1. "FM-47" vs. "FM-45"
2. Dyed vs. Undyed Prime

3. Effect of Precure (preliminary study only)  
 Panels made with 1/8-.002 expanded, unprimed aluminum honeycomb core, 0.625" thick; 24S-T3 alclad facings,  
 0.016" thick; three "FM-47" tapes under top (test) facing. Facings cleaned in hot alkaline and sodium dichro-  
 mate-sulfuric acid solutions (conditions were not necessarily optimum).

PANEL NUMBER	ADHESIVE WEIGHTS #/Sq. Ft. (2 sides only)	THREE-INCH PEEL DATA						FACING-PRIME * Identifications * Peeling Adhesive Thickness M-1-47"	All the skins primed here were warmed and then brush-coated. The coating was dried immedi- ately after coating with a hot air gun. No precure unless otherwise noted.
		Average (Two Specimens)		Average of Group	Low Reading Pct. of Average		Percent Failures at Facing		
		Inch-Lbs.	Inch-Lbs.	Ad	Co				
306	.193	.0021	187	181	92	30	70	a	Undyed (Control)
334	.177	.0021	195	92	30	80	80	a	Dyed (3 grams "OIL RED 'O'" added to each gallon of 1:1 mix of "FM-47" & thinner)
339	.184	.0016	160			70	b		
307	.188	.0026	186	175	91	25	75	c	
335	.196	.0018	132	93	25	75	75	d	
340	.186	.0018	159	85	25	75	75	d	
308	.193	.0023	156	153	81	20	80	e	Undyed
336	.137	.0023	159	90	20	30	30	e	M-45
341	.187	.0013	142		30	70	70	f	
309	.191	.0019	162	173	86	20	80	g	Dyed (3 grams "OIL RED 'O'" added to each gallon of 1:1 mix of "FM-45" & thinner)
337	.185	.0019	134	74	91	20	80	g	
342	.173	.0019	172		25	75	75	h	
310	.201	.0018	165	155	83	20	80	i	Undyed, Precured 35 minutes at 325°F.
338	.195	.0013	167	82	20	35	55	j	(Exploratory study of effect of precure)
343	.193	.0018	133					k	

\* Letters refer to 10 x 18 inch sheets which were cleaned, primed, and sheared into two smaller facings, used in two 9" x 9" panels. (Scrap facings and tape used for un-peeled facing.)

TABLE 5  
EFFECT OF FACING-PRIME PRECURE ON ADHESION

**Surface Preparation:** Thorough alkaline cleaning, followed by 5 min. in agitated sulfuric acid - sodium dichromate solution, at 140°F.

**Priming:** One brush coat, "FM-47" adhesive in equal part of "FM-47" thinner, on warmed (120°F approx.) facing; dried in circulating oven @ 160°F.

**Facing Curing:** Circulating oven at 300°F, variable time.

**Panel Cure:** 5 min. at contact pressure; 60 min. at 35 psi, 345°F.

**Materials:** **Facings** = alclad 248-T3, 0.016 thick.  
**Adhesive** = Three layers heavy "FM-47" tape.  
**Core** = AL-1/8-.002 cut 0.625 thick.

Panel Number	FACING PREPARATION				THREE-INCH PEEL DATA**				Remarks
	Prime Weight (one side) #/Sq. Ft.	Pre-cure Minutes at 300°F.	Storage* after Priming-Days		Avg. In-#	Low Reading	Percent Failures		
			Before Précure	After Précure			Pct. of Avg.	Adhesion at Facing	Cohesion at Facing
401	.002	None	—	3	211	92	50	50	
397	.003	2	--	3	193	91	50	50	
398	.003	5	--	3	200	90	30	70	Average of peels = 209 inch-lbs.
399	.002	15	--	3	219	95	15	85	
400	.002	60	--	3	223	87	10	90	
409	.002	None		17	200	91	50	50	
405	.002	2	--	17	180	93	45	55	
406	.002	5	--	17	202	93	40	60	Average of peels = 197 inch-lbs.
407	.002	15	--	17	202	89	30	70	
408	.002	60	--	17	199	83	10	90	
410	.002	5	17	--	197	88	40	60	
411	.002	5	17	--	193	81	40	60	

\* Seventeen day storage periods consisted of seven days wrapped in Kraft paper and ten days exposed to laboratory atmosphere.

\*\* Two three-inch-wide specimens per panel in 4" drum, autographic tester.

TABLE 6.

EVALUATION OF PROTECTION TO FACING PRIME  
AFFORDED BY LAMINATED POLYETHYLENE INTERLEAF

**Surface Preparation:** Thorough alkaline cleaning followed by 3 minutes in agitated sulfuric acid - sodium dichromate solution at 160°F. One minute cold rinse.

**Priming:** One brush coat "FM-47" adhesive in equal part thinner on warmed facing, dried gently with hot air gun. Average prime weight=0.002 lbs/sq.ft.

**Polyethylene Application:** Paper-backed poly. pressed to half of each facing with blotter stock pads at 200°F; 2 min. at 10 psi, then 2 min. at 50 psi. (First cycle did not cause polyethylene to adhere)

**Contamination:** Exposed halves of facings covered with fingerprints by six persons, after precure. (Four panels only)

**Panel Cure:** 5 min. at contact pressure, 60 min. at 35 psi, 345°F.

**Materials:** Facings = Alclad 24S-T3, 0.016 in. thick  
Adhesive = Three layers of heavy "FM-47" tape  
Core = Al-1/8-.002 cut 0.625 in. thick

TEST NUMBER	FACING PREPARATION		THREE-INCH PEEL DATA								PEEL RATIO  Exposed Protected	REMARKS		
	Contamination	Precure at 300°F.	Protected Area				Exposed Area							
			Avg.	Failure at Facing		Avg.	Failures at Facing							
571 570	Fingerprinted (after precure)	none "	175 181} 178	50 45	50 55	158 170} 164	55 30	45 70	92	Ratio of peels: Precured prime No pressure	1.8			
		2 min. "	187 182} 185	50 45	50 55	180 162} 171	35 30	65 70	93					
565 566	None	none "	173 179} 176	55 50	45 50	164 167} 166	50 55	50 45	94	Ratio of peels: Precured prime No pressure	1.8			
		2 min. "	198 189} 194	50 50	50 50	192 171} 184	50 60	50 40	94					

SECTION I - Continued

C - EXPLORATORY EVALUATIONS OF SANDWICH ADHESIVES:

Table 7, at the end of this discussion, shows the adhesives, methods of application, and curing cycles used by several of the major sandwich manufacturers covered in the "Survey of Existing Methods", in April 1953. Three basic types of formulations are represented here. The "FM-47" supported film and liquid system was selected for use as a test vehicle in this project because the greatest amount of detailed "process specification" data collected in the survey was found to apply to its use.

The usual criterion used in selecting an adhesive for sandwich bonding is the Military Specification based on lap-shear bonds. There is much evidence compiled in this project, and by other agencies, to suggest that the specification in itself is not an adequate criterion for sandwich-bonding adhesives. A number of adhesives that display acceptable properties in terms of a specification based on lap-shear tests have given generally poor results when used in sandwich bonding. It is understood from outside sources that the converse might also be true, i.e. that some adhesives that are suitable for use in sandwich are unable to qualify under the lap-shear specification.

There are a number of fundamental differences between the conditions of honeycomb-sandwich bonding and continuous-surface bonding. A honeycomb-sandwich bond is essentially a network of filleted "T" joints. The extreme edges of the aluminum-foil cell walls present a negligible surface area for adhesion, and for the transmission of bonding pressure through the resin. Although the flowing and filleting characteristics of the adhesive formulation are of little importance in continuous-surface bonds, it is essential that sandwich adhesives flow, without the external application of pressure, into the corners formed by the facings and the cell walls. Furthermore, honeycomb sandwich bonds have substantially more bulk or mass, and have large free surface areas for the evaporation of solvents and reaction products.

Several exploratory investigations of adhesives were performed in the project. The intent in performing these investigations was not to attempt to define or qualify the properties of individual formulations, but to obtain some indication of the general suitability of various types of formulations for sandwich bonding. In most cases the investigations are not sufficiently complete to give a fair evaluation of the merits of any individual formulation. Table 8 shows peel and tensile strengths observed in panels made with various adhesive systems. First among these is "422" (Shell Development Corp.). This adhesive, developed under military sponsorship, exhibits unusually high lap-shear properties at high heat. The tabulated results indicate that the flatwise tensile strengths obtained from sandwich bonds made with "422" tape are of generally high order. Peel strengths on the other hand are in a consistently low range, and do not appear to be influenced by adhesive weight, or to a large extent by cell size. It should be noted that all of the "422" panels represented in this tabulation had high adhesive weights, even though a single layer of tape was used in the bonds without primers.

I - C, Continued

Before leaving the discussion of the "422" formulation, reference should be made to the curves in Figures 23 and 24. Here the flatwise tensile and peel strengths of panels made with "FM-47" and "422" are shown plotted as a function of test temperature. It is apparent that "422" retains a considerable amount of its strength at temperatures as high as 500°F. It should also be noted that lap-shear bonds made from the same formulation retain higher percentages of their strength at these temperatures, according to results published in other reports. The flatwise tensile strength of the "FM-47" bonded panel drops off relatively steeply. The percents of strength retained by "FM-47" bonded panels at various test temperatures are also significantly less than the percentages retained in lap-shear bonds made with the same formulation. It is of particular importance to note that the "FM-47" bonded panel was cured in a cycle which is believed to be optimum for obtaining high heat properties (see Part D of Section I).

Figure 24, in which the relationship between peel strength and test temperature is plotted, shows that the low peel strengths inherent in "422" bonds do not increase as test temperature is increased. "FM-47", on the other hand, shows a maximum peel strength at approximately 150°F. The subsequent drop-off at higher temperatures is relatively unimportant in view of the fact that the flatwise tensile values at higher temperatures are of a low magnitude.

It may be noted in Figure 24 that both of the "FM-47" "peel vs. test temperature" curves show very steep upward slopes at room temperature, suggesting that the peel strengths at reduced temperatures might be critical.

In an attempt to upgrade the peel properties of the "422" formulation, a special tape with a loose-weave scrim cloth was used in one panel. The fabric used in the standard tape has a very close weave, and it was thought that this might have been a possible cause for the low peel strengths observed in this formulation. The special lot of tape made with open-weave "scrim" cloth was of unusually heavy weight, and it is significant to note that no improvement in strength was brought about by either the change in cloth or the increase in weight. It appears that in very rigid formulations of the type represented by "422" adhesive, bond strength is not sensitive to bond weight, contrary to the results observed with less rigid formulations. This conclusion is confirmed by the results observed when the weight of the "unfilled epoxy" formulation was varied. Peel strength in this instance showed no correlation with bond weight; the effect of bond weight on flatwise tensile strength was not clear.

Four adhesives in Table 8 are of the "epoxy" type, or modifications thereof. The first, "EPON VIII" (Shell Chemical Corporation), showed generally high values of flatwise tensile strengths, and relatively low values of peel strengths. This characteristic is typical of most epoxy formulations which have not been plasticized in some manner.

I - C, Continued

Three conditions were incorporated in the "EPON VIII" panels. In panel No. 402 the adhesive was applied directly to the facings, and no primes or fabric reinforcements were used. In panel No. 403, adhesive was spread onto cheesecloth stretched over the facing. This modification was observed to bring about an increase in peel strength; tensile strength appeared to have been downgraded, however. In panel No. 404 the adhesive was again spread over cheesecloth, but in this instance, both the facings and the core had been primed with "FM-47", in the belief that peel strength might be upgraded. Although a slight improvement in peel strength was in evidence, it is doubtful that this could be attributed to the addition of the prime, since the peel failure was cohesive, in all cases.

The "epoxy modified with 'THIOKOL LP-3'" was tested in the belief that it might exhibit a good "filleting" action. As a general rule, it is very desirable that a sandwich adhesive tend to "fillet" or "gather" at the corners formed by the cell walls and the facing. This region is the only part of the bond stressed as the panel is loaded, and it is structurally and economically desirable to confine the adhesive here. The "'THIOKOL-modified-epoxy" adhesive displayed good filleting characteristics but its peel strengths, with and without a scrim cloth, were low. Since tensile strengths were satisfactory, a further development of this type of adhesive to develop higher peel strength might be justified.

The adhesive designated as "unfilled, clear epoxy" displayed the filleting characteristic but was very brittle. It also displayed another characteristic, which would rule it out of any sandwich bonding application. At curing temperature (which in this case was of a very low order) the adhesive was lowered in viscosity to a point where it flowed down the cell walls. The majority of adhesive was found later to have deposited on the lower facings. In panel No. 72, a scrim cloth was added in the belief that the flow might be inhibited, and peel strength might be upgraded. Although some of the adhesive at the top facing remained filleted to the fibers of the cloth, the majority ran down the cells, as before. Peel strength remained at a low value, indicating that fabric reinforcements have limited value as stress-relieving agents in brittle sandwich adhesive bonds.

The "experimental rubber-epoxy-phenolic" formulation was a pilot, or preliminary blend, which was tested on the theory that it might develop self-filleting characteristics. No filleting was in evidence, and both the peel strength and tensile strength were observed to be low. A higher peel was obtained on a second panel made with a scrim cloth and a higher weight of adhesive, but the tensile values remained at a very low value. The experiment cannot be construed to rule out this general type of formulation for consideration as a sandwich adhesive.

The first of the two unsupported films, represented in Table 8 as from Manufacturer "A", displayed relatively low flatwise tensile strengths. The peel strengths were in an acceptable range, where a core prime was used in conjunction with the film. The second formulation showed low strength values in both flatwise tensile

I - C, Continued

and peel even though the core was primed. Both films showed a tendency to curl away from the cell walls during the cure. This fact probably accounted for the very low tensile and peel values observed in Panel No. 95, in which no primes were used. The addition of a prime brought about substantial increases in both the peel and flatwise tensiles of Panel No. 160, but the curling effect was still in evidence, and the film was not being utilized in the area of fillet. In Panels No. 252 and No. 303, an attempt was made to restrain the adhesive from curling by inserting a glass scrim cloth between the facing and the core. Although the scrim cloth prevented the film from curling, bond strength was not substantially upgraded by this modification. The addition of cloth in this instance did not simulate the properties of a supported film, since the resin was not consolidated to the fabric, but was merely restrained from curling by the external forces exerted by the fabric. Because of the above characteristics, it would appear that adhesive formulations in the form of unsupported films are at a disadvantage in honeycomb-sandwich bonding unless there is sufficient flow at the curing temperature to cause filleting to the core, and flow to the facings.

During the evaluation of the effect of curing pressure (Part D of this section) it was found that the cloth imparted a definite resilience to the bond during the cure. The separation of core-cell wall and facing brought about by the presence of the fabric is believed to provide a significant amount of stress relief, which increases the resistance of the structure to impact loading, and to peeling loads. While no observations of impact strength, or fatigue life were made in this project, it is believed that peel strength is related to these properties, and the use of a fabric reinforcement is justified on this basis alone. It has been stated by one manufacturer that by doubling peel strength of the bond, the service life of a panel can be extended tenfold. Another airframe manufacturer has performed sufficient tests to conclude that unbonded areas 3/4 inches in diameter do not affect the performance of the structure, as long as a peel-resistant bond is used. This characteristic of "high-peel" adhesives is a manifestation of their ability to prevent the propagation of failure in the bond.

It will be recalled that a "tape" system was selected in preference to a liquid system for use as a test vehicle in this project, because of the increasing acceptance of tapes in industry. This selection was made with the knowledge that tape systems did not develop the highest strength-weight ratios in flatwise tensile strength. Liquid systems have been used extensively in sandwich bonding in the past, but have become almost obsolete in favor of systems in which a fabric reinforcement is used. In making the change, the industry was influenced by considerations of production economy, and reliability, as well as by a belief that higher peel strengths were required. In actuality, the higher cost of supported films as compared to liquids tends to cancel the economies realized in reducing the amount of labor involved in applying the adhesive correctly. In the exploratory evaluations, several panels were made with FM-47 liquid without the addition of

I - C, Continued

tape, to obtain some knowledge of their general characteristics. The panels made here demonstrated the fact that high flatwise tensile strengths may be realized in a relatively low range of total adhesive weight when a liquid system is used. Only two of these panels were tested for peel strength, but both had unusually high total adhesive weights for "liquid only" bonds. The peel strengths of these panels were in a very low range compared with the peel strengths of panels made with a comparable weight of "FM-47" supported film. Had the two panels made with typically light liquid bonds been tested in peel, it is believed that the values would have been below the acceptable minimums specified by most manufacturers. It appears that a choice of a tape system in the project, in preference to a liquid system, was justified on the basis of the inherently higher peel strengths developed by tapes.

Both of the panels made from the formulation designated in Table 8 as "low-cost experimental vinyl-phenolic" had relatively heavy bonds, but developed relatively low peel strengths. The tensile strengths were in an acceptable range. In fabricating these panels, an attempt was made to duplicate the conditions used in making the supported film "FM-47" panels, used as a test vehicle in the project. The use of a cloth in this instance did not assure a high order of peel strength. This cannot be assumed to be general for this type of formulation, since properties may be varied by changing the proportions of the particular combinations of resins.

Table 9 at the end of this discussion shows the results of an evaluation of the "NARMTAPE 103-45" supported film using the "NARMCO 2021" priming solution. It was felt that the extensive use of one formulation, "FM-47", in this project should be augmented with a semi-comprehensive evaluation of some other major sandwich adhesive to determine if the effects of adhesive distribution, cell size, etc. were the same in either case. This particular adhesive also warranted investigation on the basis of its elevated temperature properties.

The effects of cell size, core-prime weight, and test temperature on the bond strengths developed by "NARMTAPE 103-45" are shown in Table 9. Figures 19 and 20 at the end of this discussion show graphically the effect of core-prime weight upon peel strength and flatwise tensile strength. The ratio of peel to flatwise tensile strength was found to be high with this adhesive. Both "actual" values and "specific" values are shown in the graphs. It is apparent that core-prime weight and cell size have the same effects here, as were observed with the "FM-47" supported film. The appearance of this supported film was generally similar to that of "FM-47", except that a fabric of closer weave was used in the "NARMTAPE" system. Tape weight was not varied in this evaluation, since only one nominal weight was available. This weight, 0.047 lbs/sq.ft., is in a range which (on the basis of the "FM-47" results) should give nearly optimum flatwise tensile strength-weight ratio, but which would probably be below optimum in its ability to assure consistency of quality under conditions of poor core-thickness tolerance, or substantial variations in core-prime weight.

I - C, Continued

The liquid solution, "NARMCO 2021", was applied to the cores used in these panels in the hand-operated roller coater, described in Section II - A, and Appendix I of this report. At a solids content of 15%, this liquid in undiluted form was of relatively low viscosity. Although low viscosity is usually considered to be an advantage in the mechanized application of adhesives, it was found in this case to be a disadvantage, in that there was some tendency for the adhesive to flow down the cell walls. The condition was not obvious, and would ordinarily be disregarded under production conditions. It has been found, however, that the depth of the core-prime is an important parameter in determining the strength properties of the bond. The number of passes observed to be required for applying a given weight of core prime was higher than that required for "FM-47". Since it is desirable to have as high a solids content as possible, to reduce the number of passes required in priming the core, it would be preferable to have this formulation supplied at a higher solids content, and a correspondingly higher viscosity.

The elevated-temperature properties of "NARMTAPE 103-45", shown in Figures 21 and 22 at the end of this discussion, indicated that a significant percentage of the room-temperature flatwise tensile strength was retained at 240°F. Peel strength showed some reduction as temperature was increased, but this was unimportant in view of the high overall level of peel strengths available from this formulation. An extrapolation of the peel and tensile strengths vs. temperature characteristics shown in the graphs to lower temperatures would suggest that this adhesive might be very suitable for low-temperature applications.

Returning again to Table 9, it may be seen that the types of failures observed in the peel tests were influenced by core-prime weight and by test temperature. Increases in core-prime weight tended to cause a shift from an adhesive failure at the cell walls, to a cohesive failure between the tape and the core. This trend is the same as was observed in the "FM-47" results. Increases in test temperature caused the failure to become more cohesive in nature in the "NARMTAPE" elevated-temperature test results.

In the comprehensive evaluations of "FM-47" tape systems, cell size was observed to have an important effect on both peel strength and flatwise tensile strength. Generally speaking, the magnitudes of these properties were inversely proportional to cell size. Some of the adhesives represented in this table do not appear to show this characteristic in such a striking manner. Cell size was varied as a parameter in the evaluations of "422", "FM-47" liquid, and "unfilled clear epoxy" (Table 8). In the case of "422", tensile strength showed a very small increase. Some improvement in both properties was brought about in the panels made with "FM-47" liquid when cell size was decreased. (A small cell size offers an additional advantage where liquid systems are used, in that more surface area is available for the application of the liquid.)

The unfilled clear epoxy evidenced no improvement in peel strength when cell sized was decreased; no accurate comparison could be drawn from the flatwise tensile strength results. The results obtained from the evaluation of "NARMTAPE 103-45" (Table 9) indicated that the bond strengths developed by this relatively non-rigid formulation were strongly influenced by cell size. In general, the cell size probably has a more pronounced effect on the properties of the bond where a low-modulus adhesive is used.

It should be pointed out that "creep" or "long-time loading" tests were not performed in this project. Creep strength undoubtedly represents an important criterion in the selection of adhesives for sandwich bonds; possibly more so than in the case of continuous surface bonds. Although the results of elevated temperature flatwise tensile and/or elevated-temperature flexural shear tests probably give a secondary indication of creep strength, no definite conclusions may be drawn from the work in this project as to the creep resistance of individual formulations or types of formulations.

In Appendix VI to this report, an exploratory determination is made of the correlation between shear strength in the bond and flatwise tensile strength, using "FM-47". The results indicated that a correlation existed, but that the relationship between the properties was not necessarily the same for all formulations, test temperatures, or degrees of cure. In view of the fact that shear strength is the ultimate criterion of most sandwich bonds, and that flatwise tensile strength does not necessarily bear the same relationship to shear strength in all formulations, it is doubtful that flatwise tensile strength in itself would be reliable as a criterion for use in selecting adhesive formulations for sandwich bonding.

#### CONCLUSIONS:

The conclusions derived from the work in this section may be summarized as follows:

- (1) The use of a "supported-film" system in preference to a "liquid-only" system upgrades peel strength.
- (2) Strength-weight ratio, in the flatwise tensile test, is usually reduced by the use of a supported film.
- (3) Adhesive formulations having sufficient flow at curing temperature to produce filleting at the cell walls without "run-down" from the upper facing would effect the most efficient adhesive distribution. A "supported-film" adhesive of this type, having adequate levels of peel, tensile, and creep properties, would be desirable for honeycomb-sandwich bonding.
- (4) Unsupported films exhibit disadvantages in comparison to supported films in their tendency to sag or curl away from the cell walls, and in their inability to afford fabric reinforcement to the bond.

I - C, Continued

- (5) The use of smaller cell size upgrades peel and tensile strengths. Cell size does not have a large effect on peel strength where relatively brittle formulations are used, however.
- (6) There is reason to believe that some adhesives which display high peel strengths at room temperatures may be deficient in peel strength at reduced temperatures.
- (7) There is an optimum range of viscosity for adhesives applied to the core as a prime by roller coating methods. Low viscosity may not assure that the prime stays within a definite limit of depth on being applied, whereas it is generally known that there is a practical upper limit on viscosity imposed by the successful operation of the coating machine.
- (8) There is reason to believe that the elevated-temperature properties of sandwich bonds, in terms of percent of room temperature strength retained, are generally below those which exist where the same adhesives are used in lap-shear bonds. (This conclusion is known to apply in the case of the "422" high-heat formulation, and in the case of "FM-47" supported film.)

TABLE 7

ADHESIVES, METHODS OF APPLICATION, AND CURING CYCLES USED BY SEVERAL ALUMINUM HOMEICOB-SANDWICH MANUFACTURERS AS DISCLOSED BY SURVEY OF EXISTING METHODS CONDUCTED IN APRIL 1953

(Order shown here has no relation to that shown in other survey tables.)

FACING-PRIME	CORE-PRIME	TAPE OR FILM	CURING CYCLE	REMARKS
"FM-47" Liquid Sprayed, Air Dried	"FM-47" Liquid Roller-coated, Air Dried	"FM-47" Tape	Preheat 3-8 Min. at 5% of bonding pressure, Cure 20 Min. at 305°F	None
"NARMCO M3C" Sprayed Forced-Air Dried	"NARMCO 2105-30" Hand-Rolled	"MARITAPE"	Pre-heated steel plate placed over sandwich under vacuum	Curing procedure considered unsatisfactory.
Sprayed "FM-47" Dyed -Fully Cured	Sprayed "FM-47" Dyed -Fully Cured	"EPON VIII" Spread on cheese-cloth at layup.	Vacuum + Autoclave = 50 psi	Contoured parts only.
None	"NARMCO P2" (Dyed) Roller Coated Air Dried	"MARITAPE"	300-325°F. 10 psi 20 - 40 Minutes.	Flat Panels (1-6 Panels in single-opening press)
"SILA-BOND A" Hand-Brushed, Cured	"SILA-BOND A" Roller-coated, Air Dried	Undisclosed	1/2 hour at 300°F Double-opening press	Large, Flat Panels
"FM-47" Spray and Brush 2 - 3 coats, Air and oven dry	"FM-47" Brushed & Roller-coated Air Dried	"FM-47" Tape	1:4 Min. preheat, 20 minutes at 300°F 2:3 Min. preheat, 15 minutes at 225°F	None
"PLYCOZITE 117-C" Sprayed Air Dried	"PLYCOZITE 117-C" Hand Roller or Glue Spreader. Air Dry.			"Heavy-bead" technique

TABLE 8  
EXPLORATORY EVALUATIONS OF VARIOUS  
BETAL ADHESIVES IN RESTORATIONS

Notes: 1. Fading claimed by control methods in hot alkaline and acid solutions.  
There cloth support is used, band weights include weight of cloth.

2. "MURRAY 10-40" and "75-47" tape evaluated elsewhere.

Explanation of Patients:

A = Adhesive

AC = Abduction and occlusion adhesives

C = Cements

Schreiber: \* Between facing and base

: Between core and base

Patient Number	Adhesive	Resinite	DENT	CURE	ADHESIVE METHODS	THERMO-DYNAMIC						PLASTIC TESTS						
						TESTING			TESTING			TESTING			TESTING			
						Spec.	Avg.	Spec.	Avg.	C	G	A	G	C	A	G	C	
170 glass	"75-47"		-	-	1/4	-	10	335	128	.044	-	.265	.26	113	16	0	P.E.	
206 resin	Reported		-	-	1/4	-	30	330	122	.044	-	.265	.27	113	50	504	1090	
276 resin	1/16	Special Tape	-	-	1/4	-	40	330	120	.044	-	.265	.27	113	50	624	920	
251 glass	(Shell) Dent.		-	-	1/8	-	40	330	120	.044	-	.265	.27	113	50	605	710	
207 -	(Gent.)		-	-	1/8	-	40	330	120	.044	-	.265	.27	113	50	1000	3300	
402 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	264	10	60	P.E.
403 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
404 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
405 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
406 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
407 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
408 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
409 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
410 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
411 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
412 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
413 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
414 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
415 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
416 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
417 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
418 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
419 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
420 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
421 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
422 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
423 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
424 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
425 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
426 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
427 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
428 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
429 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
430 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
431 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
432 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
433 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
434 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
435 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
436 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
437 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
438 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
439 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
440 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
441 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
442 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
443 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
444 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
445 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
446 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
447 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
448 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
449 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
450 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
451 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
452 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
453 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
454 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
455 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
456 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
457 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
458 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
459 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
460 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
461 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
462 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
463 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
464 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
465 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
466 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
467 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
468 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
469 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
470 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267	10	60	P.E.
471 glass	"75-47"		-	-	1/4	-	50	200	-	-	-	.075	.147	19	267			

**TABLE 9**  
**EXPLORATORY EVALUATION OF "MAGTAP" 103-45" WITH MARCO 2321 LIQUID PRIME**

Facings: Alclad 24S-T3, .016 thick, cleaned by control process, brush-primed, dried.

Core: Expanded type al 1/8-.002 and al 1/4-.003, primed in roller coater to depth of 1/32 inches approx., dried.

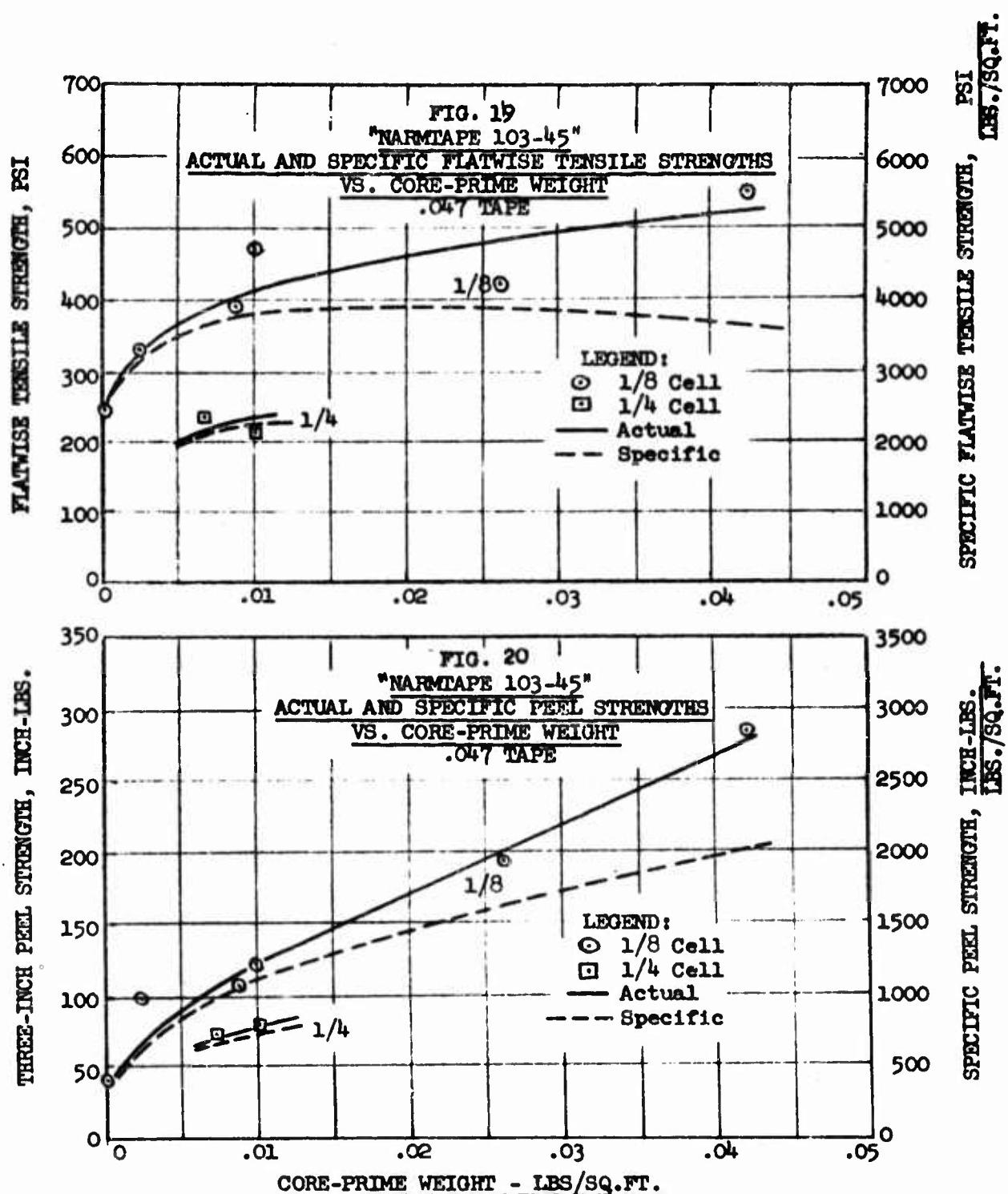
Drying Cycle: Air dry 2 hours, oven dry 15 minutes at 180°F.

Panel Cure: 2 hours at 345°F., 35 psi.

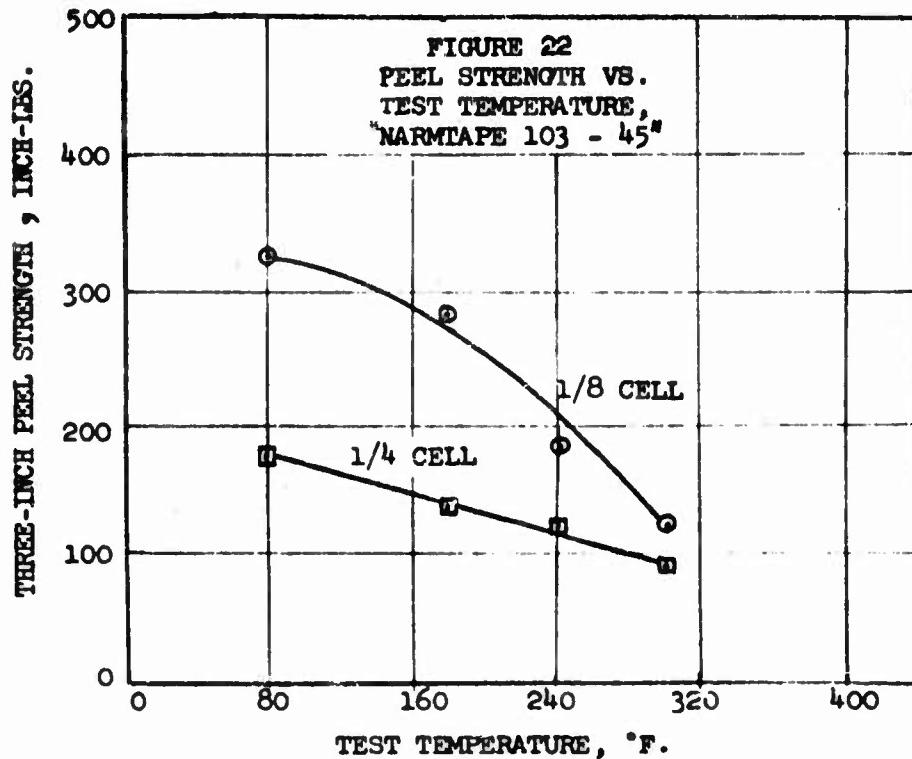
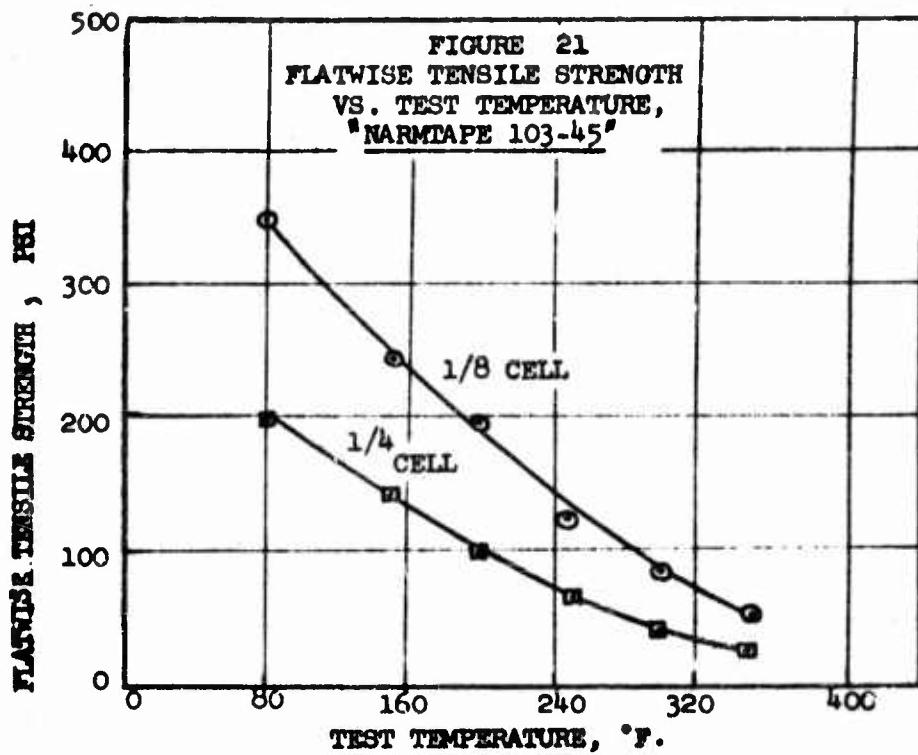
PANEL NUMBER	CUT SIZE	ADHESIVE WEIGHTS	THREE-INCH PEEL						FLATWISE TENSILE										
			TEST TEMPERATURE, °F. (60, RT, 50, 55, 65)	PET. IN # OF AVG. #/SQ. IN.	PET. IN # OF AVG. #/SQ. IN.	ACTUAL AVG.	LOW REG.	SPECIFIC AVG.	PERCENT FAILURES (All failures between tapescore)			TEST TEMPERATURE, °F. (60, RT, 50, 55, 65)	PET. IN # OF AVG. #/SQ. IN.	PET. IN # OF AVG. #/SQ. IN.	ACTUAL AVG.	LOW REG. PCT. OF AVG.	SPECIFIC AVG.	PSI #/IN <sup>2</sup>	FAILURES**
									AD+	Co	Co								
554		.016	.003	.005	.006	.005	39	.77	410	90	10	--	242	93	2550	Ad & Co			
550		.016	.003	.002	.002	.006	97	.73	1010	10	70	20	326	96	3400	Co			
552	1/8	.014	.003	.009	.009	.009	106	.90	1070	10	15	75	386	96	3900	Co			
551		.050	.002	.010	.010	.015	119	.87	1050	30	55	15	465	94	4100	Co			
614		.018	.005	.026	.026	.120	192	.91	1600	--	50	90	416	88	3470	Co			
611		.019	.006	.042	.042	.145	285	.94	1970	--	10	90	540	95	3730	Co			
553	1/4	.018	.003	.007	.0103	.103	72	.92	700	70	30	--	230	97	2250	Co			
555		.018	.002	.002	.010	.107	Room	.79	84	780	50	50	--	211	97	1970	Co		
549*	1/8	.016	.003	.019	.013	.113	Room	129	--	1140	20	75	5	Room	354	--	3140		
							180	109	--	10	60	30	150	252	--	2230			
							240	70	--	5	55	40	200	198	--	1760			
							300	47	--	--	50	50	250	134	--	1190			
											300	88	300	88	--	780			
												350	58	--	515				
548*	1/4	.018	.003	.007	.103	.103	Room	67	--	650	10	30	60	Room	205	--	1990		
							180	53	--	5	30	65	150	145	--	1410			
							240	46	--	--	15	200	200	107	--	1040			
							300	34	--	--	10	90	250	65	--	630			
												300	46	300	46	--	450		
												350	30	350	30	--	290		

\* Results of Panel Nos. 548 & 549 plotted vs. test temperature, separately. Both results represent average of one peel and 2 tensile specimens at each temp. (Other averages based on 2 peels, 6 tensiles per panel.)

\*\* All flatwise tensiles failed between tape and core.



FIGURES 19 & 20: Room-temperature flatwise tensile and peel strengths (actual and specific) of "NARMTAPE 103-45" supported film with "NARMCO 2021" liquid prime, vs. core-prime weight. (From Table 9) Cure: 2 hours at 345°F, 35 psi. Facings: .016 alclad 24S-T3, primed to 0.003 to 0.006 lbs/sq.ft. Weights are dried, uncured. Core-prime weight includes both sides.



Figures 21 & 22 : Peel and flatwise tensile strengths of "NARMTAPE 103-45" supported film with "NARMCO 2021" liquid prime vs. test temperature. Specimens tested as they reached temperature. (From Table 9). Facings: Alclad 24S-T3, .016" thick. Cure: 2 hours at 345°F, 35 psi.

FIGURE 23

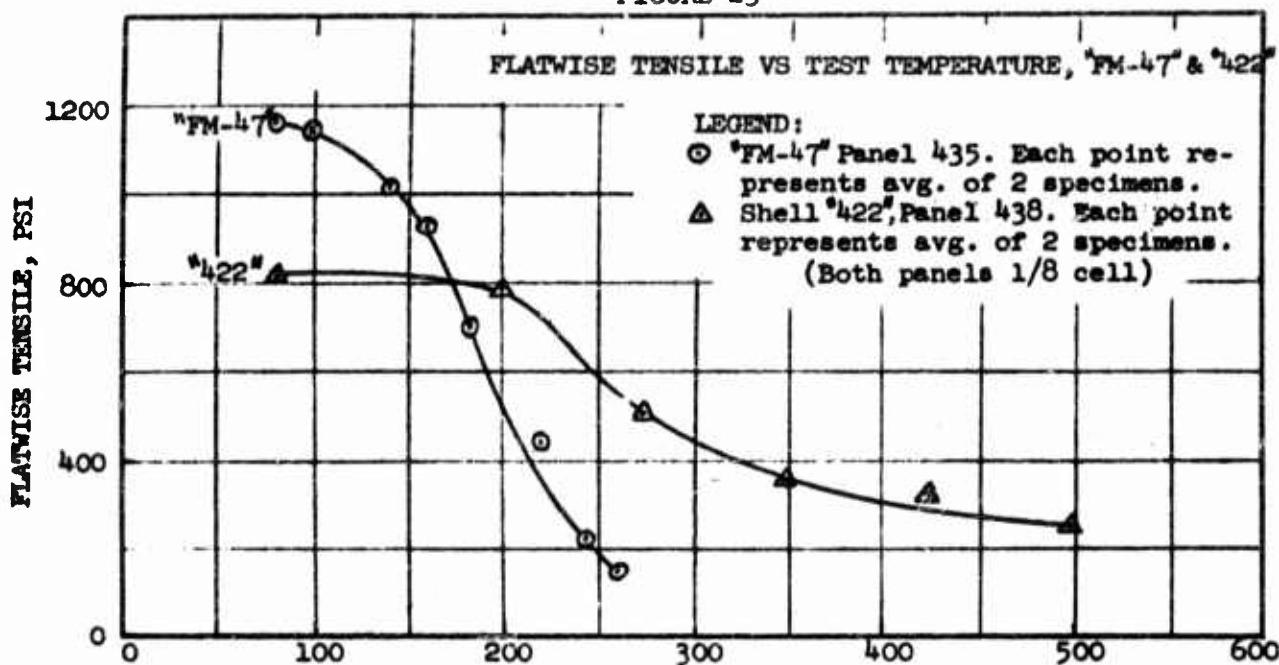
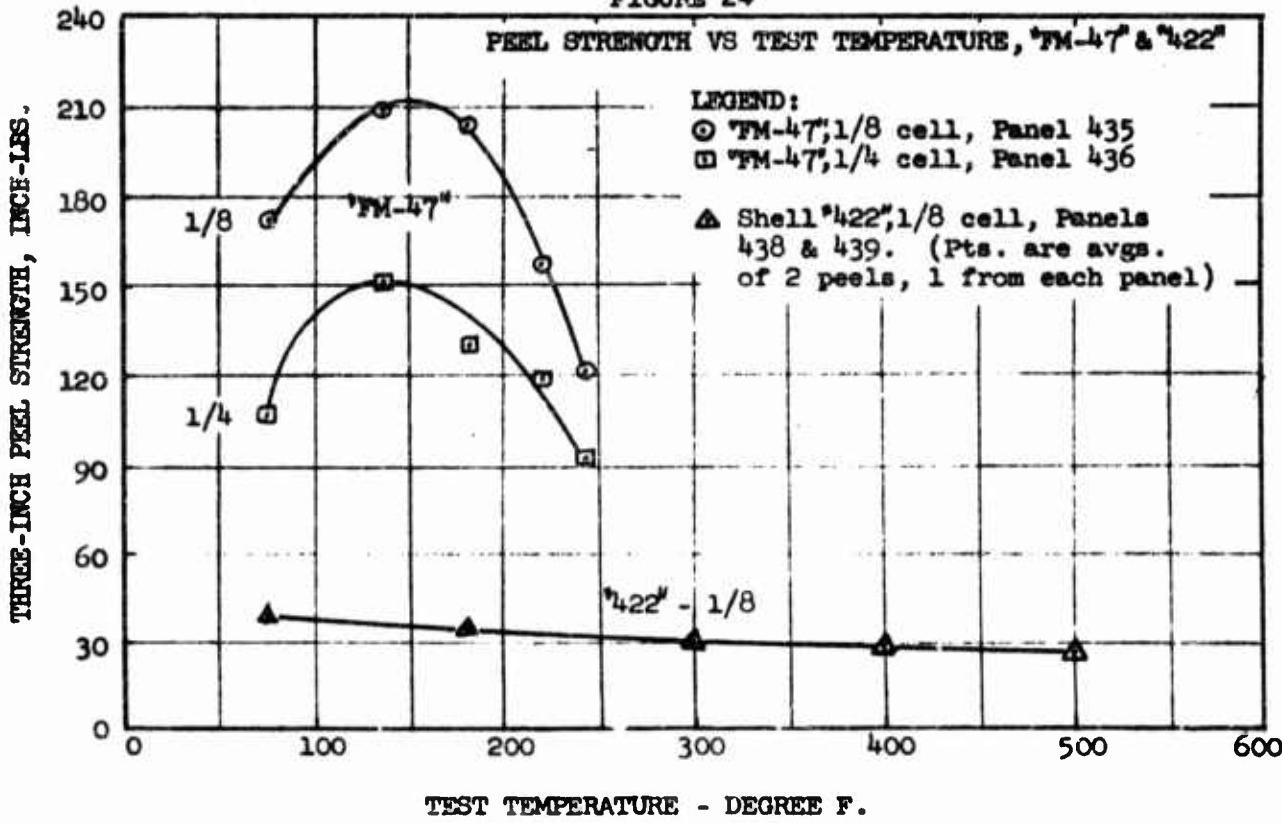


FIGURE 24



Figures 23 & 24: Peel and flatwise tensile strengths of "FM-47" and "422" vs. test temperature. (Specimens tested as they reached temperature; 0.016 alclad 24S-T3 facings)  
 "FM-47" cure: 5 minutes at 2-4 psi, 345°F; 60 minutes at 35 psi, 345°F. Adhesive wt. = 0.155 lbs/sq.ft. approx.  
 "422" cure: 35 psi; 30 min. at 160°F; 30 min. while temperature increased from 160° to 330°F; 30 min. at 330°F. Adhesive wt. = 0.138 lbs/sq.ft. approx.

## SECTION I - Continued

### D - CURING-CYCLE VARIABLES

This phase of the project is presented in two parts. The first includes studies of the effects of curing time and press temperature on the strength of honeycomb sandwich bonds. The second part deals with the effects of pressure, and pressure irregularities, and presents methods of alleviating the effects of the irregularities. Applicable tables and graphs are presented at the end of each individual discussion.

#### 1. Effects of curing time and temperature on "FM-47" bond strength:

In the course of previous work, it appeared that the curing cycle which was recommended for "continuous surface" bonds made with "FM-47" was too short in duration, and too low in temperature to give optimum results in sandwich bonding, particularly where the structure is to be used at elevated temperatures. It was believed that this condition was not peculiar to "FM-47" only, but was general for almost all metal adhesives which are used in both honeycomb sandwich and continuous surface bonding. To insure adequate curing, the control curing cycle for "FM-47" bonded panels in this project was established as 55 to 60 minutes at 35 psi and 345°F, after a five-minute preheat at two to four psi. This decision was made despite the fact that survey information (Table 7, Part C, Section I) indicated that some sandwich manufacturers who used "FM-47" were curing for 15 to 20 minutes at temperatures of 300° to 325°F. In order to qualify this deviation from recommended practice, a comprehensive evaluation was performed. The results of the evaluation presented here established that the control curing cycle used in the project was very nearly optimum.

The results of the study are presented in Table 10 and in Figures 25 through 28. The choice of the 1/4-inch cell size and a light adhesive bond was made to keep the bond strength low enough to preclude any chance of failure in the bonds between the flatwise tensile blocks and the specimens, in the elevated temperature tests. The combination of light tape and large cells kept the peel strengths at a relatively low value, and tended to cause most of the failures to occur between the tape and the core material. In order to partially compensate for minor variations in the weights of the bonds, all results were multiplied by the ratio of average/actual total cured adhesive weights.

Curing time was the independent variable in this study, while press temperature, preheating time, and post-curing time were parameters. In this particular program, a curing temperature of 325°F was made the control, rather than 345°F, the temperature used in the other phases of the project.

The five-minute preheat on Panels 329 and 330 was omitted to determine if there might be some obvious effect. Although one of these panels gave a very high peeling torque, no other apparent trends were observed, and the points were plotted in the graphs without special identification.

The exploratory evaluation of the effects of omitting the preheat on "FM-47" bonded panels was too limited to be conclusive. It is possible, however, that the practice of preheating of sandwich panels may be detrimental to bond strength in the case of some adhesives (including "FM-47"). Evaluations presented in Part 2 of this discussion indicated that the proximity of the core cell-wall edges to the facings was a function of the curing pressure in a supported-film system. If the bond has received a partial cure in the "preheat" portion of the pressing cycle, the abrupt application of full pressure, and the resulting movement of the core with respect to the facings, may cause a compressive failure in the bond. Although the integrity of a bond that has failed in this manner will be substantially restored by the further application of heat, it is unlikely that maximum strength will be achieved. Very short preheat cycles may be required to develop maximum bond strengths in some fast-hardening formulations.

The widespread use of a preheat at contact pressure is usually considered to be justified to promote the escape of vaporized solvents from the interior of the panel. In many cases the cell walls in aluminum honeycomb panels have been ruptured and facings have been "blistered" by excessive pressures exerted by entrapped gases. The advent of perforated honeycomb core minimized failures of this type but did not eliminate them, primarily because the perforations were occasionally omitted throughout parts of the cores, particularly in thin slices. Improvements in the control of honeycomb manufacturing processes have made this type of defect a rarity. Another justification which is claimed for the use of the contact-pressure preheat is the desirability of allowing the facings of large panels to undergo thermal expansion, without mechanical interference from the bonding tool. The physical data and survey information collected in this project have not established conclusively that the use of a preheat at contact pressure is mandatory in the bonding of honeycomb sandwich panels. Since the preheat represents an additional process detail which must be kept under control, and since it probably tends to downgrade bond strength, manufacturers should give some consideration to its elimination.

Three of the panels in the "325°F" group in Table 10 were made with oven post-cures (no pressure) after a press cure was performed. One of these panels (number 333) was post-cured after being in the press only ten minutes. Its strength did not appear to be impaired in any way by this unusual curing procedure. Conceivably, such a curing schedule might be of value where the hot-press capacity of a plant was at a premium while extra oven space was available. It is very likely that thermal warpage on large panels would become a critical consideration in such a case, however. The post-cured panels were plotted with the others without special identification.

An examination of the peel curves (figure 25) shows that peel strength was generally upgraded substantially as curing temperature was increased. An optimum peel strength is generally in evidence at press times of the order of one hour. It should be pointed out that the relatively steep drop-off of the "345°F" curve is based on only one reading. Although the 275°F peel readings were generally higher than those at 300°F, the two groups were plotted as one curve to avoid confusion. The fact that two of the panels cured at 275°F gave peel strengths equivalent to those of panels cured at 325°F would appear to make the peel test unreliable as a means of detecting degree of cure.

The trend of peel failures in Table 10 (325°F cures) indicated a maximum ratio of cohesive/adhesive strength at curing times of the order of one hour. Very short and very long cures brought about a more cohesive type of failure.

The room-temperature flatwise tensile curves (Figure 26) show a complicated series of inflections which are probably partly attributable to experimental error. The minimums occurring at total curing times 20 to 60 minutes on most of the curves appear to reflect a natural trend, however. The curves indicate that very short cures give higher values than cures of the normal order of duration, a fact which would make the flatwise tensile test at room temperature unreliable as a means of detecting degree of cure. The flatwise tensile results at heat (Figures 27 and 28) do not show these minimums. Although heat resistance is generally enhanced by increases in curing time or temperature, there appear to be several exceptions to this rule. At a test temperature of 180°F, a cure of 60 minutes' duration at either 325° or 345°F gives substantially the same flatwise tensile strength. Further increases in time do not appear to upgrade heat resistance appreciably. At a test temperature of 240°F, however, the same sets of conditions give entirely different strengths. Again it should be pointed out that the drop-off of the 345°F flatwise tensile curve (240°F test temperature) is based on the results of only one panel.

Although the relative magnitudes of the tensile strengths at elevated temperatures may give some secondary indication of the resistance to creep deflections, creep resistance itself was not evaluated in the project.

The color of the bonds was observed to change from lemon-yellow to dark amber, as curing times and/or temperatures were advanced. Although the color in the center of the panel appeared to give some general indication of the degree of cure, it should be noted that the outer edges of most "FM-47" panels usually tend to darken more than the interiors.

Panels cured at low temperatures retained some odor of solvent but, in the experience of the contractor, odor is often a deceiving indication of cure. In an undocumented test, some scraps from panels having varying degrees of cure were immersed in "FM-47" thinner overnight. The bonds in the panels cured at low temperatures showed complete deterioration while those cured at higher temperatures still had considerable residual strength. It is possible that a controlled exposure to solvent or solvent fumes, followed by a flatwise tensile test, might be of some use in evaluating the degree of cure of sandwich bonds (vented core only) made with this type of adhesive.

It is apparent that the recommended cures of 300° to 325° in conjunction with times of 20 to 30 minutes are not sufficient to develop the optimum properties of "FM-47" in sandwich bonding. There is no evidence in this program suggesting that these cycles are not adequate for continuous-surface bonding. The need for more advanced cures on sandwich bonds is probably due to the large bulk of the bond in comparison to the thin plane of adhesive in continuous-surface bonds, and also to heat-transfer differences. This is probably true for most adhesives that are used in both types of bonds.

I - D, Continued

It is often argued that temperatures of the order of 350°F are prohibitive because of their detrimental effects on the temper of heat-treated aluminums. A paper entitled "Reheating of 24S and 75S Sheet", by J. A. Nock Jr., published by the Aluminum Company of America, indicates that the curing cycles used in sandwich bonding may either upgrade or downgrade the yield and ultimate strengths of the 24S alloy, depending upon the exact combination of time and temperature. A cure of from 10 minutes to one hour at 350° downgrades the yield and tensile strengths of 24S-T3 by approximately 2000 to 2500 psi. Further increases in time upgrade the strength of 24S-T3. According to this paper, the properties of the 75S-T6 alloy are downgraded by extended cures at 350°F. Since the inflections in the curves from which these observations were made are very complicated, the reader should not attempt to extrapolate the above information to other conditions.

The conclusions from this phase of the work are as follows:

1. Honeycomb sandwich structures appear to require longer cures and higher curing temperatures than do "continuous surface" bonds using the same adhesive.
2. Extensions of curing time and temperature tend to upgrade the properties of the bond at elevated temperatures.
3. A curing temperature of the order of 350°F would not be seriously detrimental to the properties of 24S-T3, but the 75S-T6 alloy is susceptible to overaging at this temperature. The effect of curing time and temperature on the strength of aluminum cannot be generalized, however.
4. A total curing time of 60 minutes at a temperature between 335° and 350°F provides a good compromise between optimum properties and production economy on sandwich bonds made with "FM-47". This curing schedule is not necessarily applicable to other formulations.
5. Preheating at contact pressure may actually be detrimental to honeycomb-sandwich bond strength where adhesives having rapid hardening characteristics are used, but the practice is claimed to have other benefits which may dictate its use, in most cases.
6. Post-curing in an oven after a short press cure has the same effect as a long press cure, where "FM-47" or similar types of adhesives are used.
7. Tensile and peel-strength tests at room temperature do not give a reliable indication of the degree of cure of sandwich bonds made with "FM-47".

TABLE NO  
EFFECT OF CURING-CYCLE, "FM-47"

Core:  $1/4\text{--}.003$  Aluminum  
Facing:  $.016^{\prime\prime}$  alclad 24S-T3, cleaned by control method.

Note: Peel and tensile results have been plotted vs.  
total time at cure, elsewhere.

Explanation of Failures:

A = Adhesion

AC = Adhesion & cohesion mixed

C = Cohesion

Curing Temperature, °F.	Total Curing Time, Minutes	CURING-CYCLE		Panel No.	ADHESIVE WEIGHT DATA					THREE-INCH PEEL ROOM TEMPERATURE						CORRECTED* FLATWISE TENSILE AVERAGE, PSI (All failures cohesion, tape to core) TESTED AT:				
		Preheat & Postcure Times Included in Total			Tape Wt. (1 side)	#/sq.ft.	Cover-Prime (2 sides)	#/sq.ft.	Facing-Prime (1 side)	#/sq.ft.	Total Cure Wt. (2 sides)	#/sq.ft.	Corrected Average, lbs./inches.	PERCENT FAILURE						
		Pre	Post											Peeling	Cored	Core	Room Temp.	180°F	240°F.	
250	20	5	-	379	.051	.024	.002	.119	52	-	-	-	80	20	-	363	36	-		
	35	5	-	380	.049	.024	.002	.120	48	-	-	-	80	20	-	450	83	-		
	125	5	-	381	.051	.024	.002	.120	38	-	-	-	90	10	-	459	97	-		
275	20	5	-	382	.053	.024	.002	.122	65	-	-	-	75	25	-	484	95	-		
	35	5	-	323	.054	.026	.002	.126	68	2	2	-	83	13	-	456	113	-		
	65	5	-	322	.054	.026	.003	.129	56	-	-	-	80	20	-	460	127	-		
300	20	5	-	324	.054	.026	.002	.123	50	-	-	-	85	15	-	497	234	-		
	35	5	-	316	.056	.024	.002	.128	50	-	-	-	100	-	-	467	285	35		
	125	5	-	315	.055	.024	.002	.133	52	-	-	-	78	22	-	517	340	37		
325	10	5	-	317	.054	.024	.002	.124	54	-	-	-	88	12	-	541	384	73		
	10	5	-	383	.051	.024	.002	.118	63	-	-	-	100	-	-	588	213	29		
	20	5	-	321	.056	.026	.002	.129	56	-	-	-	95	5	-	527	306	36		
35	5	-		328	.056	.026	.002	.121	64	-	-	-	98	2	-	568	243	44		
	35	5	-	319	.055	.024	.002	.126	63	-	-	-	95	5	-	513	333	61		
	65	5	-	326	.056	.024	.002	.125	83	-	-	-	82	18	-	490	348	59		
35	65	5	-	325	.055	.024	.002	.123	70	-	-	-	93	7	-	516	416	81		
	65	-	-	329	.055	.024	.002	.122	70	-	-	-	72	26	-	579	419	87		
	65	-	-	330	.055	.024	.002	.121	89	-	10	-	12	78	-	550	322	103		
375	5	-		318	.055	.026	.002	.125	76	-	-	-	83	17	-	587	438	105		
	125	5	-	320	.054	.024	.002	.119	64	-	-	-	85	15	-	588	438	153		
	125	5	-	327	.055	.026	.002	.118	64	-	-	-	25	74	-	570	442	154		
375	125	5	120	331	.056	.024	.002	.120	70	-	-	-	70	30	-	575	428	184		
	125	5	165	332	.056	.027	.002	.124	58	-	-	-	70	30	-	540	389	144		
	125	5	175	333	.056	.024	.002	.120	74	-	5	-	90	5	-	563	424	201		
345	10	5	-	384	.050	.024	.002	.118	76	-	-	-	100	-	-	570	344	60		
	20	5	-	314	.055	.026	.002	.131	95	-	5	40	55	-	-	523	293	40		
	35	5	-	312	.054	.024	.002	.120	77	-	-	-	95	5	-	551	380	90		
	65	5	-	311	.051	.024	.002	.114	83	-	2	10	83	5	-	508	417	133		
	125	5	-	313	.054	.024	.001	.118	61	-	-	-	90	10	-	551	431	123		

\* Corrected to average adhesive line weight (.123 lbs./sq.ft.) by multiplying by ratio of average/actual wts.

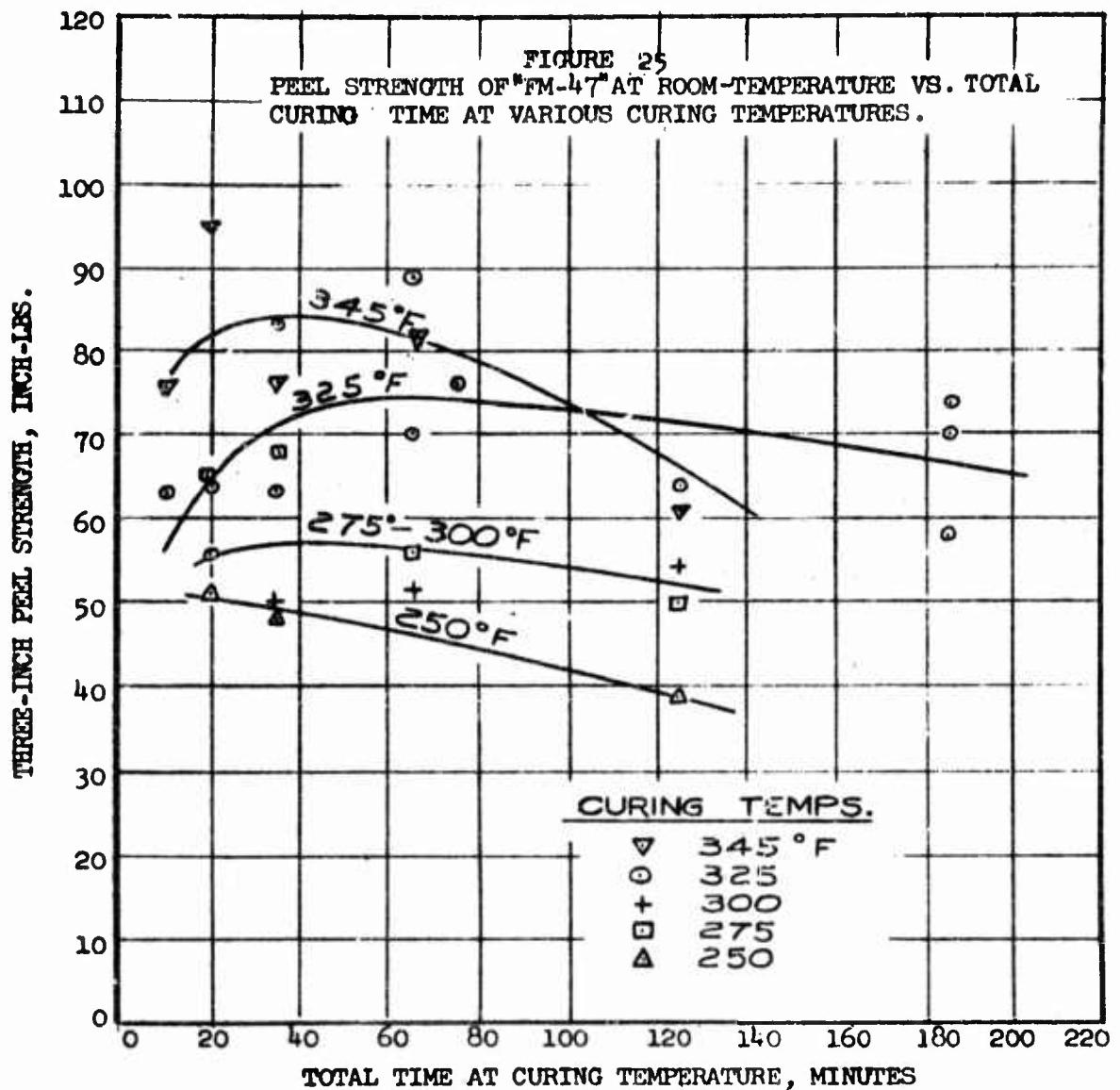


FIGURE 25 : Room temperature peel strength of "FM-47" bonds to 1/4 inch cell honeycomb, as affected by curing time and temperature.  
(From Table 10 )  
Facings: Alclad 24S-T3, 0.016" thick.

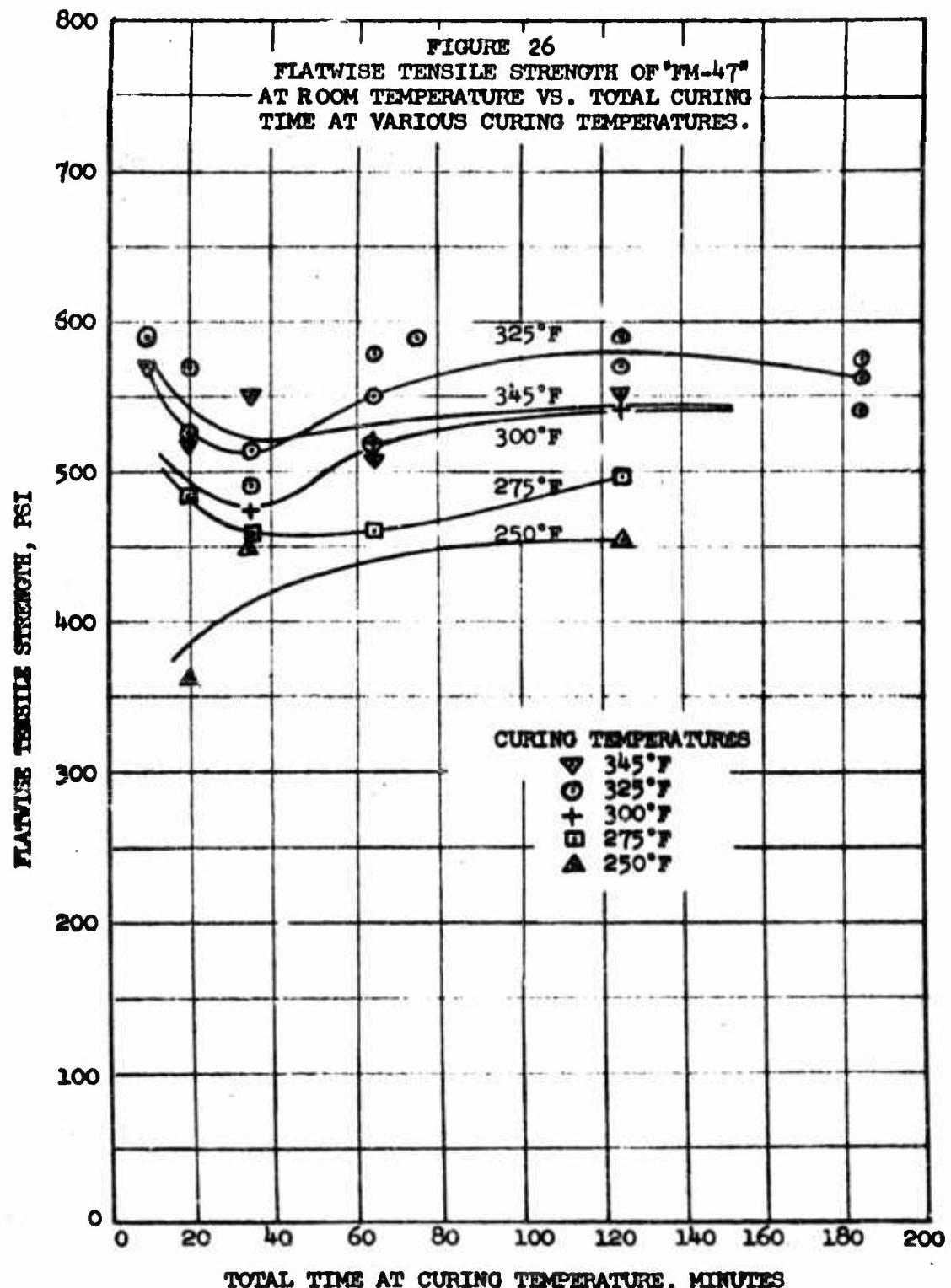
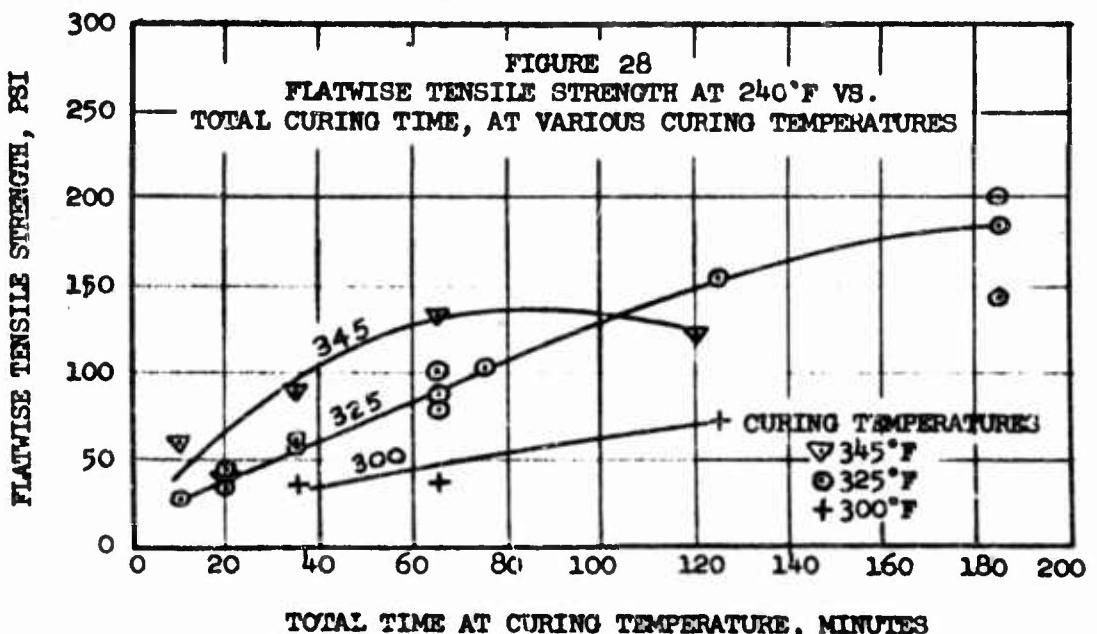
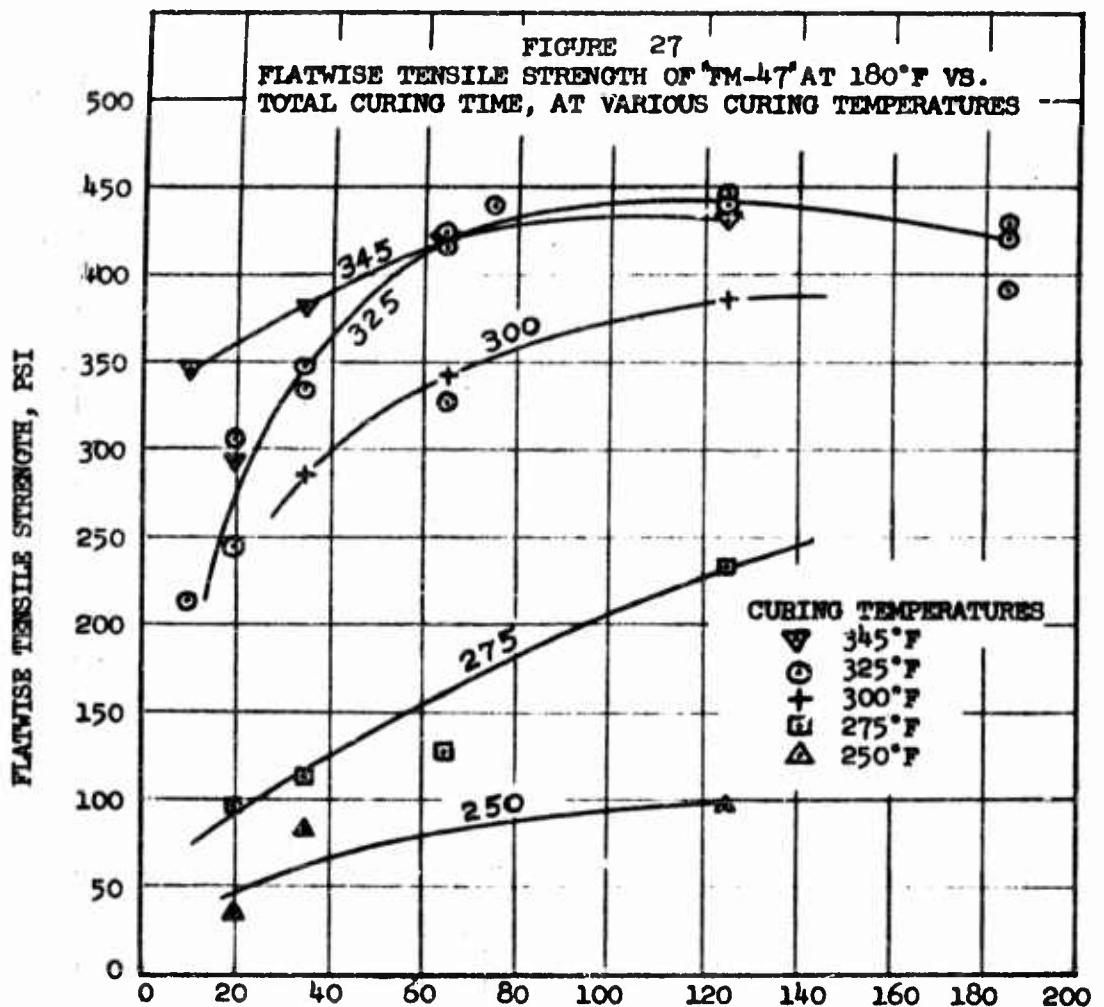


FIGURE 26 : Room temperature flatwise tensile strengths of "FM-47" bonds to 1/4-inch cell honeycomb, as affected by cure time and temperature. (From Table 10).



FIGURES 27 & 28 : Elevated temperature flatwise tensile strengths of "FM-47" bonds to 1/4-inch honeycomb, as affected by cure time and temperature. (From Table 10)

## SECTION I

### PART D - Continued

#### 2. Effects of Curing-Pressure Variables; Selection of Press Pad Materials:

The second phase in the investigations of curing variables dealt with curing pressure, core-thickness deviations, and methods of equalizing curing-pressure variations over the surfaces of honeycomb sandwich panels.

Two of the problems which relate to the equalization of curing pressure are warpage in the curing fixture, and the control of the thickness of flat honeycomb. These problems are discussed in Part E of this section ("Core Material") and in Section II, Part E ("Curing Presses").

Table 11 at the end of this discussion shows tabulated survey results illustrating the "press-loads" used by a number of honeycomb sandwich manufacturers. Firms "A" and "E" in this tabulation used padding materials of some kind for the purpose of equalizing mechanical pressure. Three other firms used only kraft paper between the cauls and the facings. The primary purpose in adding paper was to prevent the cauls from becoming contaminated with adhesive, not to equalize pressure.

The range of curing pressures observed in use, in the survey of existing methods, was from 10 psi to 200 psi. These pressures were usually not selectively applied to various honeycomb core densities but were chosen according to the individual preferences of the manufacturers. Where high curing pressures were in use, "stops" (rectangular steel bars) were often inserted in the press to prevent the hot-plates from exerting crushing pressures on the thicker portions of the composite. Most sandwich manufacturers felt that the resilient properties of supported films tended to equalize pressure and improve the consistency of bond strength.

In general, the survey results indicated that some work should be done in the evaluation of "press-pad" materials, since no two manufacturers appeared to favor the same type of material, and since some of the materials were relatively expensive. It also appeared that some evaluation should be made of the effect of curing pressure and of core-thickness deviations, in view of the fact that these two parameters appeared to be important factors in the rejection of production parts.

Table 12 shows the tabulated results of a program in which curing pressure, height of core-thickness deviations (difference in thickness at splices), tape weight, and cell size were adjusted with respect to each other. Figures 30, 31, and 32 show graphically the effect of curing pressure on bond strength and bond thickness. The panels made in this evaluation were cured without the use of pads, and were made with three individual pieces of core material, milled before expansion to controlled thickness, and butt-jointed together within the composite.

The effects of curing pressure were observed on the outer (thick) portions of the panels only. The bond strengths observed in these portions were used as control references in interpreting the significance of the magnitudes of the strengths developed in the center portions where the core material was below thickness.

The following observations were drawn from the results presented in Table 12:

- (1) Curing pressure had little effect on the strengths developed in the regions where the core was below thickness.
- (2) Curing pressure had a direct effect on the clearance, or gap, between the edges of the cell walls and the facings in the areas where the core was thick. The clearances observed here were not a function of the unit weight or thickness of the supported film, but were probably a function of core density and of the type of cloth reinforcement used in the film. The cloth appeared to have imparted some resilience or compressibility to the composite, in resisting the penetration of the edges of the cell-walls while curing pressure was being applied. It is probable that the clearance would have approached zero had no cloth reinforcement been used.
- (3) Curing pressure had little or no observable effect on peel strength, but had a definite effect on flatwise tensile strength. The variation in tensile strength was probably only indirectly a function of curing pressure, the direct influence being the clearance between the core and the facing, which was itself a function of curing pressure. Intimate contact between the facing and the core undoubtedly promoted a more effective consolidation of the tape to the core prime, and caused the fillet to be more dense and compact.
- (4) Heavier tapes showed pronounced beneficial effects in equalizing bond strengths developed over areas in which core-thickness irregularities occurred. (It is probable that heavy core primes would have exhibited the same beneficial effects to some extent.)
- (5) Heavier tape weights and/or smaller cell sizes, tended to minimize the effects of curing-pressure variations on the consistency of quality of the bond in flatwise tensile strength. (This observation is based on the fact that all of the "flatwise tensile vs. curing pressure" curves showed the same slope, whereas the levels of these curves were raised as tape weight was increased, or as cell size was reduced.)

I - D, Continued

These results should not be interpreted to imply that a tape weighing 0.08 lbs. per sq. ft. (uncured) should become standard. In the "Adhesive Weight" evaluations, the optimum tape weight, from a "strength-weight" standpoint, was 0.05 lbs. per square foot. The evaluation represented in Table 12 and the results of other studies in the project suggested that a tape weighing 0.07 lbs. per sq. ft. would offer the best compromise between strength-weight ratio and general dependability of the bond under adverse fabrication conditions.

It is interesting to note that even though these panels were cured without the use of press pads, the facings appeared to have been pressed down slightly into the regions in which the core material was undersize. The average thickness observed in the center regions (not shown in Table 12) was approximately 0.003 inches less than the thicknesses observed in the outer portions of the same panels.

The investigations conducted up to this point suggested that a practical set of test conditions for evaluating press-padding materials should involve the use of panels fabricated with predetermined core-thickness irregularities, in conjunction with one curing pressure and one tape weight.

Before running practical evaluations of press-pad materials, extensive screening tests were performed on a wide variety of padding materials which had been used in the past, or which appeared to be potential replacements for materials in use. The results of these screening tests are shown in Table 13 and Figure 33. Samples of padding materials were subjected to static compression tests in which pressure was applied in a testing machine through ground plates. Instantaneous deflection readings were made with a dial indicator as the pressure was increased. Another reading was then taken with only the weight of the upper ground plate on the specimen, after the machine pressure was released, in order to determine the permanent deformation or "set" induced in the sample. The "deflection vs. pressure" curves of a number of these materials are shown in Figure 33. The change in deflection observed between pressures of 5 and 50 psi (arbitrarily considered to be the desired limits of local curing pressure in a typical sandwich panel) were tabulated in the third column. The amount of this difference was interpreted as the general mechanical effectiveness of the pad under room-temperature loading conditions.

In arranging the presentation of pads in the table, the changes in deflections were placed in increasing order of magnitude. It will be noted that samples of some of the materials were evaluated in this manner after having been subjected to a simulated bonding cycle in a heated laboratory press. This was done in order to obtain a secondary indication of the heat resistance and/or the re-usability of the pad. Micrometer readings were taken before and after the loads were applied, on the majority of samples.

In addition to the aforementioned tests, transient heat-flow tests were conducted to obtain an indication of the thermal insulating

I - D, Continued

properties of the pads. Special honeycomb sandwich panels having thermocouples bonded under their facings were placed between samples of the pads in a heated (300°F) press, and instantaneous readings of temperature were made at definite time intervals. The interval required for the adhesive plane to reach a temperature of 275°F was tabulated in the second column of Table 13.

Approximate costs for the materials, in cents per square foot of panel area (two square feet of padding) are also shown in the tabulation.

In general, there was a trend toward longer heating times as the effective resilience of the padding materials vs. increased. A notable exception was represented in "KIMPAK", however. This material showed relatively high deflection in view of its low cost and ability to transmit heat. The effective delay in bringing the panel to temperature which would be brought about by adding this material (assuming that the ".03" material is used), in lieu of using no padding at all, would be only about six seconds. In actuality it is possible that delays of the order of 2-1/2 to 3 minutes might be desirable from a practical standpoint, since they would permit thermal expansions in the composite to take place gradually and uniformly after the panels were introduced into the press, and would also cause more gradual release of the solvents in the adhesive. There are no data available from this project to indicate whether the rise in panel temperature should be slow or rapid for best results, but panel manufacturers would generally prefer that the panel reached temperature promptly, to conserve press time. The sample of "AEROCOR" (a sponge-like, fiber-glass, vibration-absorption material) showed the highest order of resilience. Its use would incur a delay of approximately 2-1/2 minutes in the curing cycle. Although its cost was much higher than that of "KIMPAK", it appeared to be reusable whereas "KIMPAK" did not.

The fact that the micrometer readings on the pad samples gave the same values before and after the room-temperature compressive tests were run showed that readings of this type cannot be used to determine the effectiveness of a padding material, before or after use. This limitation was attributed to the fact that the anvil pressures applied by the micrometer were always high enough to crush a given material to the same thickness, regardless of its condition.

Only one solid rubber pad was evaluated in the exploratory studies. It was learned from one source that this type of padding was relatively incompressible, except at the edges, where a slight outward flow occurred. Since the centers of the pads were effectively thicker than the edges as a result of this flow, solid rubber pads were considered to be ineffective as a means of equalizing pressures in a flat press. A further criticism of solid rubber padding materials was that their resistance to temperatures of the order of 350°F was marginal. Since there were a large number of fibrous, sheet materials, which were more compressible and less costly, rubber pads did not receive comprehensive evaluations.

It may be noted that none of the pads evaluated in this program were of the internally heated type. Although it was obvious that

I - D, Continued

flexible, resilient, heating elements were required in some of the types of fixtures used to cure contoured assemblies, their cost did not appear to be justified where flat sandwich was to be cured. It was believed that conventional "hot-plate" presses furnished the most reliable means for applying uniform temperatures, as well as uniform pressures, to flat work. Internally-heated pads are subject to failure from burn-out of the elements and it is difficult to control their temperature over their entire surface, whereas steam- or oil-heated plates are not subject to local heat-source failures and their temperatures can be controlled uniformly.

Another means of securing uniform pressure distribution on flat panels is by the use of fluid-pressure diaphragms. Although diaphragms have been used successfully in the bonding of flat parts, they were not evaluated in this project, since the ordinary hot-plate press has appeared to be the most dependable and economical means of applying pressure to large quantities of flat panels. It would be possible to use fluid-pressure diaphragms or "envelopes" in lieu of fibrous pads, in standard presses, but their use would make it necessary to carefully position each panel within a restraining frame, to prevent "blowout" of the diaphragm at unsupported areas. In addition to the danger of blowout, the use of fluid-pressure envelopes would impose additional heat-transfer and temperature-control problems which are not encountered where simpler and more economical pressure-equalizing media are used.

The results of tests conducted on several of these padding materials are shown in Table 14. As in the case of the earlier evaluation of curing pressure, panels made with controlled core-thickness irregularities were used. The same nominal tape weight (0.05 lbs. per sq. ft.) and curing pressure (35 psi; outer portions only) were maintained throughout the program. The total cured adhesive weight used in these panels was intentionally made low to give pessimistic conditions which would emphasize any beneficial effects brought about by the pads. Micrometer readings were made at the center (reduced core thickness) portions and at the outside (thick) portions of the cured panels. The differences in these two thicknesses were divided by the intentional difference in core thickness at the two locations, to give a "deflection ratio" which was a measure of the effectiveness of the padding material in equalizing the pressure over the irregularity. The press pads have been tabulated in the increasing order of this ratio, where a core-thickness irregularity of 0.020 inches was used. The "deflection ratios" of various pads showed approximately the same order of increase where a core-thickness difference of only 0.010 inches was incorporated in the panels. It is interesting to note that the deflection ratios for each pad were substantially unaffected by core-thickness difference.

Although it was thought that the peel and flatwise tensile strength in the thin center regions (expressed as percentages of the values observed in the outer regions) would increase in the same manner as did the deflection ratios, such was not the case. After the apparent resilience of the padding material, in terms of its ability to bring the unsupported portion of the facing closer to the surface of the thin section of core,

I - D, Continued

increased to a certain point, additional increases did not upgrade the strengths of the bond in the center portion. This limit of effectiveness occurred at a lower order of apparent resilience where a smaller core-thickness discontinuity was used. Thus, where a core-thickness difference of 0.010 inches can be expected, a press pad should be used, but the choice of the padding material is almost arbitrary, since most types of pads are effective at this thickness difference. Where a thickness difference of 0.020 inches can be expected, some selective judgment would be required to assure that maximum strengths in the thin areas are developed by the press pad, but any one of a number of types of pads appear to be suitable.

Since the evaluation of the effect of curing pressure (Table 12) had indicated that flatwise tensile strength was upgraded as the facings were forced into closer proximity to the core, it was surprising to observe that decreases in the facing-to-core clearance below a certain value had no effect on bond strength after a certain "deflection ratio" had been realized. The only explanation which may be offered for this characteristic of highly resilient padding materials is that the facing was not forced into its final position with respect to the thin portion of core until after the preheat at contact pressure. In the interim, the tape and the core prime became partially cured and lost some of their ability to flow and coalesce, so that when intimate contact was finally established, an optimum fillet was not produced. The phenomenon did not appear to be important enough to justify additional experimental work.

The following are a number of additional factors which might be taken into consideration in the selection of an optimum press-pad material:

- (1) The pad will be called upon to minimize the effect of non-parallelism in the press opening, as well as the effects of core-thickness irregularities.
- (2) The results of this evaluation do not necessarily represent the conditions where continuous-surface bonds are incorporated in sandwich panels; consideration should be given to more resiliant pads for panels of this type.
- (3) The indiscriminate use of highly resilient pads may cause the panels to have an undesirable outer appearance from "dimpling" of thin-gage facings in large-cell cores, or from "steps" in the planes of the facings at the boundaries of internal thickness discontinuities. ("Dimpling" was not observed in any of the panels made in this evaluation, nor were sharply defined "steps" in evidence, but the area in which the facing was pressed into the discontinuity was clearly observable as a "valley".)
- (4) Thick, heavy pads may exhibit thickness or density irregularities of the same magnitude as those which are found in the core.

I - D, Continued

- (5) The curing time and/or temperature may have to be increased where pads having very high insulating properties are used.

These arguments would dictate the selective use of press-padding materials in some instances. In general, however, a highly resilient pad is desirable.

The padding material cannot necessarily be depended upon to maintain high bond strengths in regions where the core material is below the normal thickness with all types of bonds. The results which were presented in Table 12 indicated that the most important factor in equalizing bond strength in panels having thickness irregularities was the mass or thickness of the adhesive film. It can be interpreted from the results shown in Tables 12 and 14 that, where the maximum core-thickness difference is held under 0.010 inches (corresponding to a manufacturer's tolerance of  $\pm 0.005$  inches), the use of a nominal tape weight of 0.07 lbs./sq.ft., in conjunction with the use of press-padding materials, would insure that the peel and tensile strengths in the regions where the core was thin were maintained at a level which was approximately 90%, or more, of the level of the strength in the thicker regions.

It should be mentioned that no direct evaluations of the thickness variations which are brought about by the presence of solid insert of "edging" materials, were made in this program. It can be assumed, however, that thickness irregularities in these materials have effects which are analogous to those brought about by thickness irregularities in flat honeycomb. With most adhesives, the "continuous-surface" bonds over the solid detail components require higher pressures than do the bonds to the honeycomb. At a given curing pressure, the clearance between the edges of the honeycomb cell walls and the facings (determined in this program for a limited number of core-density and pressure combinations) is less than the clearance between two continuously bonded surfaces. Where the same type of fabric extends over honeycomb and inserts of identical thickness in the same assembly, more unit pressure is then transmitted through the continuous-surface bond. If the "bond clearance vs. curing pressure" relationships were known for both types of bonds, a realistic theoretical determination could be made of the maximum allowable tolerances on the thickness of the honeycomb and the detail parts which would insure that adequate curing pressures were transmitted through both parts.

TABLE II

TYPICAL PRESS LOADS OF FIVE ALUMINUM HONEYCOMB FLAT PANEL MANUFACTURERS  
AS DETERMINED IN SURVEY OF EXISTING METHODS, CONDUCTED IN APRIL 1953

(Order bears no relation to that in other "survey" tables)

A UPPER HOT PLATE	B UPPER HOT PLATE	C UPPER HOT PLATE	D UPPER HOT PLATE	E UPPER HOT PLATE
Aluminum Caul	Aluminum Caul (Solvent-wiped between cycles)	.060" Aluminum Caul	Aluminum Caul	1/32" Chipboard used once or twice
Glass Fiber "sur- face mat" (Normal- ly re-used)		Brown Paper slip sheet (Discarded)	-	-
Sandwich	+ Sandwich	70 lb. kraft paper (Discarded after use)	-	Sandwich (Tools made of aluminum sheet used to position details)
Steel Stops (square bar) of same thickness	Steel Stops	Sandwich	-	-
Surface Mat		Slip Sheet	Sandwich	Chipboard
Caul	Caul.	Sandwich, etc. (up to six sand- wiches)	Restraining Fringes	-
Lower Hot Plate	Floating Hot Plate	Paper	-	Floating or Lower Hot Plate (May be multiple opening)
	Sandwich, Etc.	Caul	Caul	Floating or lower hot plate (May be multiple opening)
	Lower Hot Plate	Lower Hot Plate	Lower Hot Plate	

TABLE 14

STUDY OF THE EFFECTS OF TAPE WEIGHT, CELL SIZE,  
CURING PRESSURE, AND THERMOGRAPHIC  
REGULARITIES  
ON Balsawood Sandwich Panel Strength

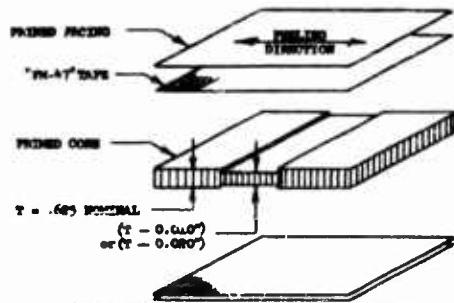
Materials: Facing: Alclad 505-T3, .016 thick, cleaned in hot  
alkaline & sulfuric-dichromate solutions,  
primed to 0.005 lbs./square foot approx.  
with uncured "TM-47".

Core: Al 1/8-.006 and Al 1/8-.003, milled be-  
fore expansion to .685, .615 & .605 inches  
thick (nom.); primed in roller coater, 0.01  
to 0.015 lbs./square foot.

Conditions: Core butt-jointed edge coated heavily with "TM-47",  
dried in place. (See sketch at right). Cured in  
9" x 9" laboratory press, without pads at 345°F  
5 min. at 5 psi, 60 minutes at (variable) curing  
pressure (Center area neglected in computing load  
to give desired pressure.)

Presentation: Values pertaining to "center" areas are shown  
below, and to the right of results from outer  
"control" areas.

FIGURE 29  
SPECIAL PANEL USED IN EVALUATIONS  
OF CURING PRESSURE VARIABLES



Specimen No.	Adhesive Weight (2 sides) lb./sq. ft.	Core Thickness inches	Cell Size inches	Curing Pressure psi	Ratio: Center Outside	Net Panel Thickness Charged to Cured Bond inches	THREE INCH PEEL DATA										FLATWISE TENSILE DATA					
							Corrected** Average (one peel each face) In-lb.		Ratio: Center Outside	Lowest Reading Average	Percentage Failures ***						Corrected** Average (N-5 Specimens)		Ratio: Center Outside	Lowest Reading Average	Failures ***	
							Average	Out			Failure A	Failure AC	Failure C	Failure C	Failure AC	Failure A	Failure B	Failure C				
587	.106 .108					.018 ---	73 33		.78	.79 --	2 5	--	98 95	--	--	--	710 643		.63	.86 .84	C Core	
588	.106 .103					1/8 8	30	.009 ---	.69	.86 --	2 5	--	100 100	--	--	--	790 687		.54	.90 .91		
589	.110 .107					100	.009 ---	94 60	.42	.76 --	2 5	--	98 100	--	--	--	896 830		.46	.96 .97		
590	.106 .100					9 ---	69 36	.58	.55 --	--	--	--	100 95	15	--	--	677 597		.89	.88 .00		
591	.105 .099					30	.010 ---	71 33	.46	.73 --	2 5	--	98 100	--	--	--	698 642		.06	.88 .00	C Core, C Face	
592	.107 .102					100	.007 ---	86 39	.45	.89 --	2 5	--	98 95	--	--	--	842 86		.11	.98 .00	C Core C Core, C Face	
593	.105 .108					9 ---	51 34	.67	.70 --	--	--	--	100 85	75	--	--	478 599		.21	.98 .88	C Core C Core, C Face	
594	.105 .108					30	.008 ---	45 27	.60	.70 --	--	--	100 100	--	--	--	586 518		.22	.88 .76	C Core	
595	.101 .098					100	.005 ---	51 28	.55	.80 --	--	--	100 100	--	--	--	686 667		.86	.91 .64		
641	.166 .161					9 ---	157 142	.90	.71 --	--	10 40	80 50	5 5	--	--	--	1060 9364		.88	.86 --		
640	.163 .152					1/8 8	30	.010 ---	210 193	.98	.96 --	80 80	70 50	5 5	--	--	--	1110 8910		.76	.98 --	
642	.160 .158					100	.006 ---	157 162	.97	.86 --	--	80 80	30 30	30 30	--	--	--	1250 9780		.78	.96 --	
655	.153 .148					9 ---	136 105	.78	.87 --	85 20	75 80	--	80 80	--	--	--	1170 6000		.51	.96 --		
603	.146 .143					30	.013 ---	177 72	.41	.90 --	--	35 35	5 60	40 40	--	--	--	12150 6000		.56	---	
656	.157 .158					100	.007 ---	193 162	.04	.71 --	--	10 40	35 35	30 30	5 51	--	--	1250 7950		.63	.94 --	
664	.153 .153					9 ---	180 84	.70	.63 --	--	20 50	80 50	60 60	--	--	--	991 3600		.60	.91 --		
663	.157 .156					30	.008 ---	115 89	.77	.79 --	--	35 35	55 50	70 60	--	--	--	600 5400		.71	.96 --	
665	.158 .158					100	.007 ---	158 111	.05	.68 --	--	15 40	60 50	25 20	--	--	--	787 6900		.66	.96 --	

\* = 2 Specimens only

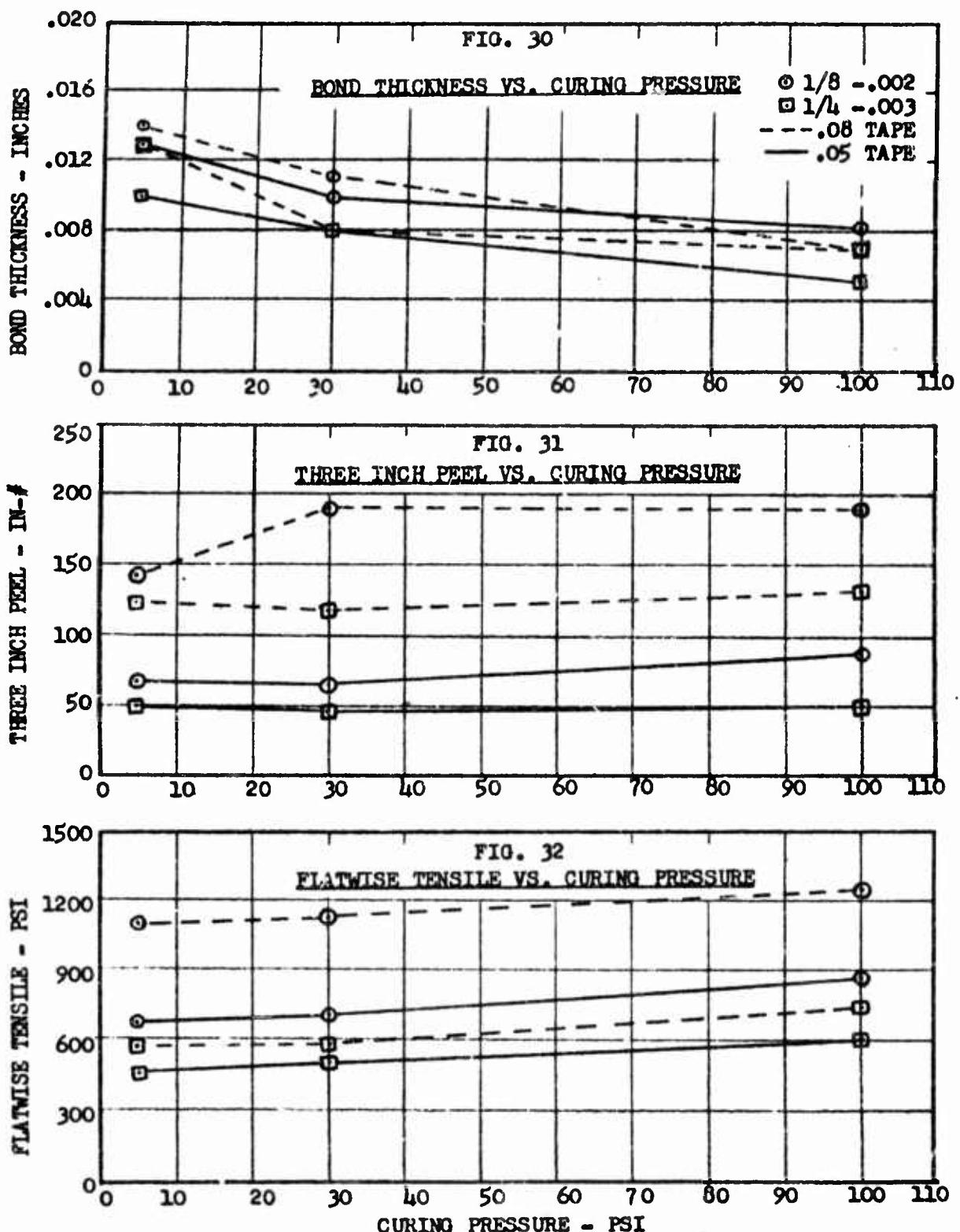
\*\* = Corrected to average adhesive line weight (.05 tape, .1050/sq.ft., .08 tape, .1560/sq.ft.) by multiplying by ratio -average + actual weights.

\*\*\* = Explanation of failure codes: A = Adhesive

AB = Adhesive and cohesive mixed

G = Cohesive

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Figures 30, 31, & 32: Bond thickness and bond strength vs. curing pressure, for two cell-sizes and two "FM-47" tape weights. (Data taken from outer, "control", portions of panels made with core irregularities. See Table 12).

TABLE 13

## PRELIMINARY EVALUATION OF PRESS PAD MATERIALS

Note: Materials are arranged in order of increasing change in room-temperature deflection, from 5 to 50 psi, (3rd column). Deflection curves for several materials plotted elsewhere.

MATERIAL DESCRIPTION (Numbers in parenthesis refer to sources listed below)	Time to change 50 mil. at press temp. minutes	Change in deflec- tion from 5 to 50 psi (Indicator)			Permanent Set after 75 psi Load (Indicator)			Avg. Micrometer Thickness .001"	Cost *	REMARKS
		As Received		After 5 min. 50 psi	As Received		After 5 min. 50 psi			
		Minutes	.001 Inch	.001"	After 5 min. 50 psi	.001"	After 5 min. 50 psi			
No Pad	0.63		0.0	---	---	---	---	---	---	Heat transfer & compression control.
Kraft Paper, 30# basis	0.67		0.16	---	0.0	---	2.7	0	0.2	
"Bag-moulding" rubber, 1/64" thick	---		0.28	---	0.2	---	16.2	0	---	
Kraft Paper, 60# basis	0.69		0.32	---	0.4	---	5.4	0	0.4	
Jute-line Paper, 90# basis	0.93		0.50	---	0.3	---	9.4	0.1	0.4	
Jute-line Paper, 130# basis	1.0		0.51	---	0.2	---	11.9	0	0.5	
Kraft Paper, 75# basis	0.78		0.74	0.24	0.3	0.3	6.6	0	0.5	
"SILASTIC CLOTH NO-20", dbl. thk. (1)	1.03		1.24	---	0.5	---	34.0	0	292	Must be pre-cured.
1/32" Chipboard	1.77		1.26	---	0.2	---	34.7	0	1.5	Not available in rolls.
"SILASTIC SIZED HD-66" (1)	---		1.8	1.9	2.0	2.0	19.0	8.0	---	
Blotter Stock	1.87		1.9	1.1	1.1	0.8	22.4	0.4	6.1	Not available in rolls.
"HICOLOR S", 500# basis (2)	---		2.2	1.9	1.2	---	49.0	---	3.0	
Paper Towel Stock, 32.5# basis	0.77		2.5	1.1	2.8	0.9	72.2	0.5	0.2	48" rolls available.
"PRES-TO-FLO", 5/32" thk. (3)	4.3		3.2	---	1.7	---	18.0	0	216	Must be pre-cured. **
"RAYCORD O", 500# basis (2)	---		3.4	1.2	2.9	---	47.0	---	3.1	
"PURAYONIER", 500# basis (2)	1.65		3.7	2.7	1.5	1.9	58.1	0.5	3.6	
Monocroven Cotton "WEBBIL M/2201" (4)	---		5.6	1.4	8.5	0.6	15.0	1.0	5.3	
"FIBEROLASS" Surfacing Mat, .020" thk., starch bound (5)	1.12		7.0	3.4	6.3	2.1	10.0	0	3.8	
Paper Towel, 2 thicknesses	---		7.2	2.4	7.8	2.6	15.0	1.0	0.4	
"FIBEROLASS" Surfacing Mat, .020" thk., Furfuryl bound (5)	1.17		7.2	0.6	6.5	1.0	8.5	0	3.8	
"KIMPAX NO.312", backed, .03" nom. (6)	0.77		10.4	1.8	18.0	3.0	8.5	0.5	0.5	Indentations in surface of backing.
"FIBEROLASS" Surfacing Mat, .020" thk., Polystyrene-bound (5)	1.02		10.5	5.2	9.0	5.2	10.0	0	3.8	
"ASTEM" press pad (7)	3.4		13.3	6.2	9.3	3.3	121	7.0	---	
"KIMPAX NO.316", backed, .06" nom. (6)	0.92		14.8	3.6	20.2	6.2	13.0	0	1.2	Indentations in surface of backing.
"PRES-TO-FLO", 5/32" thk. foil covered (3)	4.45		15.0	---	13.8	---	1470	0	216	Must be pre-cured, bulges at edges. **
"KIMPAX NO.316", unbacked, .06" nom. (6)	---		17.9	---	29.5	---	10.0	0	1.0	Tears easily.
High Density "AEROCOR" (5)	3.16		55	10.5	33.2	3.5	80	48	23.2	
Asbestos, 3/16" thk.	4.05		---	---	---	---	---	---	---	Heat transfer control only.

\* - Most of the costs represented here are not firm, and are based on lots ranging from 1000 lbs. to 1 carload. cutting and handling costs are not included.

\*\* - Ability to equalize pressure through fluid flow not evaluated here.

## SOURCES

- (1) Dow Corning Corp., Midland Michigan.
- (2) Rayonier Corp., 161 E 42nd St., New York, N. Y.
- (3) Bloomingdale Rubber Co., Chester Penn.
- (4) Kendall Mills, Walpole Mass.
- (5) Owens-Corning Fiberglass, 68 Post St., San Francisco, Calif.
- (6) Kimberly-Clark Corp., Neenah Wise.
- (7) Astem-Hill Mfg. Co., East Falls, Philadelphia 29, Penn.

COMPRESSIVE DEFLECTION - INCHES

FIGURE 33  
ROOM TEMPERATURE COMPRESSIVE  
DEFLECTION OF VARIOUS PRESS-  
PAD MATERIALS VS. PRESSURE

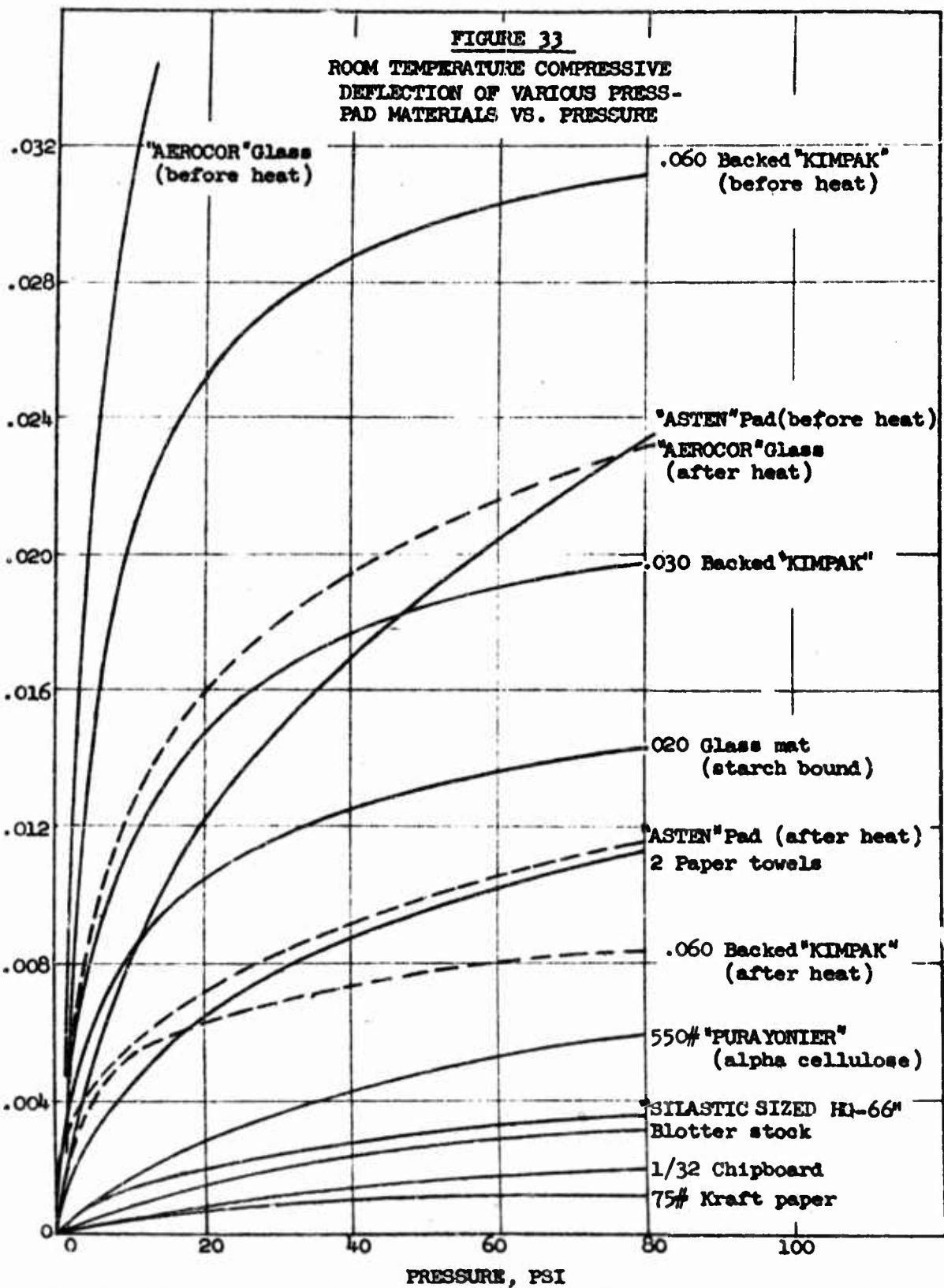
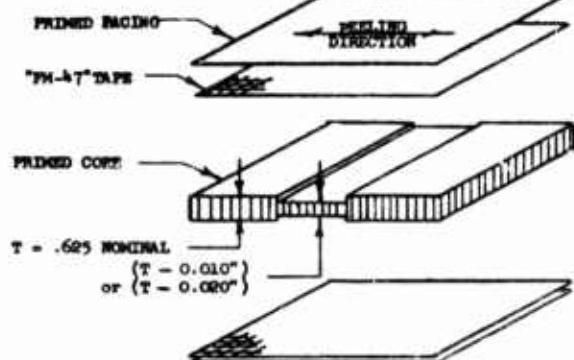


Figure 33: Compression curves for various proposed pressure-equalizing materials. Specimens pressed between flat plates in Tinius-Olsen testing machine. Deflections read from dial indicator. Dotted curves were run after pad was subjected to simulated curing cycle (5 min. at 50 psi, 350°F.).

TABLE 14  
EVALUATIONS OF VARIOUS PRESS PAD MATERIALS UNDER PANEL CURING CONDITIONS

Materials: "PM-47", 0.05 lbs./sq.ft. nominal wt.  
 Tape: Alcold 448-T3, .015" thick, cleaned in hot  
 alkaline & sulfuric-dichromate solutions,  
 primed to 0.008 lbs/square foot approx. with  
 uncoated "PM-47".  
 Core: Al 1/4-.003, milled before expansion to 0.625,  
 0.615 & 0.605 inches thick (nom.); primed in  
 roller coater, 0.01 to 0.015 lbs/square foot.  
 Conditions: Core butt-joints edge coated heavily with "PM-47",  
 dried in place. (See sketch at right). Panels cured  
 in 9" x 9" laboratory press, with various pads at  
 3kpsi; 5 min. at 5 psi, 60 minutes at 35 psi  
 curing pressure. (Center area neglected in compu-  
 ting load to give desired pressure.)  
 Presentation: Values pertaining to "center" areas are shown  
 below, and to the right of results from outer  
 "control" areas.

FIGURE 34  
SPECIAL PANELS USED IN  
EVALUATIONS OF PRESS PADS



TEST NUMBER	Pad Material	TOTAL CURED ADHESIVE WEIGHT (2 sides) /sq.in. ft.	SATURATION IN PANEL THICKNESS (%)	TOTAL CORE THICKNESS (in.)/PEEL THICKNESS (in.)	THREE-INCH PEEL							FLATWISE TENSILE	
					Corrected* Average	Ratio	Percentage Failures			Corrected Average (4 - 6 specimens) PSI	Ratio		
							Facing		Core				
					Center	Outside	A	AC	C	C	AC	A	
627	None	.106	.22	.58	--	--	--	2	--	78	20	--	510 344
		.105		37	.64		--	--	--	100	--	--	.67
639	"SILASTIC SIZED" HO-66" **	.100		47	--	--	--	--	--	100	--	--	402 435
		.101	.45	36	.77		--	--	--	93	5	--	.89
628	2 Paper towels	.106		48	--	--	--	--	--	85	15	--	530 427
		.105	.45	41	.85		--	--	--	100	--	--	.80
632	"PURAYONIER" Alpha-Cellulose	.010	.108	61	--	--	--	2	98	--	--	--	540 472
		.106	.56	48	.79		--	--	--	93	5	--	.87
631	.03 "KINGPAK" backed	.104		57	--	--	--	--	--	85	15	--	504 468
		.103	.78	45	.79		--	--	--	90	10	--	.80
635	"MASTER" Press Pad	.102		58	--	--	--	--	--	85	15	--	464 434
		.102	.80	49	.85		--	--	--	100	--	--	.90
637	High Density" AEROCOR"	.103		56	--	--	--	--	--	100	--	--	578 450
		.102	.78	51	.91		--	--	--	100	--	--	.78
626	None	.103		59	--	--	--	--	--	85	15	--	493 153
		.100	.16	25	.42		--	--	--	100	--	--	.31
638	"SILASTIC SIZED" HO-66" **	.101		52	--	--	--	--	--	95	5	--	440 181
		.098	.50	26	.50		--	--	--	55	--	--	.41
629	2 Paper towels	.107		56	--	--	--	--	--	80	20	--	533 367
		.104	.58	41	.73		--	--	--	100	--	--	.69
633	"PURAYONIER" Alpha-Cellulose	.020	.107	51	--	--	--	--	--	95	5	--	512 347
		.105	.58	35	.66		--	--	--	100	--	--	.68
630	.03 "KINGPAK" backed	.103		54	--	--	--	10	80	10	--	--	583 460
		.100	.74	40	.74		--	--	--	100	--	--	.79
690	" " "	.101	.75	46	--	--	--	--	--	95	5	--	475 287
		.101	.76	38	.82		--	--	--	100	--	--	.61
634	"MASTER" Press Pad	.106		54	--	--	--	2	98	--	--	--	548 365
		.102	.80	32	.59		--	--	--	100	--	--	.67
679	" " "	.104	.80	39	--	--	--	--	--	90	10	--	413 282
		.101	.79	30	.77		--	--	--	100	--	--	.68
680	" " "	.100		53	--	--	--	--	--	100	--	--	535 360
		.76		43	.81		--	--	--	100	--	--	.68
636	High Density" AEROCOR"	.106		66	--	--	--	5	95	--	--	--	554 463
		.102	.85	49	.74		--	--	--	95	5	--	.84
689	" " "	.102	.80	52	.81		--	--	--	95	5	--	464 292
		.76		42	.78		--	--	--	100	--	--	.73

\* - Corrected to average adhesive line weight (.103/sq.ft.) by multiplying by ratio - average + actual weights  
 \*\* - Leaves brown stain on facing.

## SECTION I, Continued

### E - CORE MATERIAL

This section includes exploratory evaluations of various types of aluminum honeycomb cores, the effects of storing and cleaning cores, and methods of controlling core thickness.

There are two basic types of honeycomb cores, "expanded" and "corrugated", produced at this time. These classifications are derived from the method of manufacture. In "corrugated" cores the hexagonal cell configuration is established by preforming or corrugating the foil. The projecting nodes are then coated with adhesive and butted against similarly coated nodes on adjacent strips of foil, under heat and contact pressure. Blocks of honeycomb fabricated in this manner usually measure about ten inches in the direction normal to the plane of the bonded nodes. These blocks are bandsawed into slices of the desired thickness. "Expanded" cores (used as a test vehicle in this project) are made by bonding the nodes under heat and high pressure, before any forming of the metal is performed. Many sheets of foil are bonded together in this way to form solid blocks from one to three inches thick. Slices of desired thickness are band-sawed from these blocks, and are then pulled ("expanded") into relatively long slices of honeycomb, the hexagonal cell configuration being formed automatically in the process.

In order that the node bonds be strong enough to withstand expansion stresses, it is necessary to chemically clean the foil used in the "expanded" core before the adhesive is applied. "Corrugated" cores may or may not be cleaned, since the cleaning is not a prerequisite of the manufacturing technique.

Generally the two cores can be distinguished by the fact that the material sawed in the unexpanded condition retains sharp-edged cell-walls, while "corrugated" material has a roughened, burred edge. The appearances of the two types may be reversed where expanded type cores are sawed after expansion, and corrugated cores are milled to thickness. Thickness tolerances of the order of 0.005 inches can be maintained on flat honeycomb cores, either by sawing in the unexpanded condition or by sawing open core "blocks" or "logs" into slightly oversize slices which are then sized to thickness in precision rolls. An experiment discussed in this section indicated that it was impractical to roll expanded cores to thickness.

Cores of either type are almost always supplied with vent holes or perforations in the cell walls to permit the escape of solvents during the panel cure.

The densities of honeycomb cores are proportional to foil thickness, and inversely proportional to the size of the cells. Generally speaking, expanded cores can be made in smaller cell sizes than can corrugated cores.

I - E, Continued

The direct effect of cell size on bond strength was observed in the Adhesive Weight program (Part A, Section I). The bond strength was found to be about inversely proportional to the cell size at a given set of bond-weight conditions. In roller-coating experiments (discussed later in this report) it was found that the weight of prime adhesive which can be applied in a single pass is also nearly inversely proportional to cell size of the honeycomb.

Physical properties such as compressive strength and shear strength are primarily a function of core density, and are not affected to a large extent by cell size.

Cell size affects the local degree of stabilization of thin gage sandwich facings under compression. In tests conducted at Forest Products Laboratory (reference 38), it was found that the cell size of the honeycomb should be no more than approximately ten times the thickness of the facings, if the full properties of aluminum in compression are to be realized. Related to this characteristic, is the tendency for thin-gage facings to "dimple" or "mark off" into the depressions formed by the cells, as a result of excessive pressure or shrinkage of the adhesive under cure. "Dimpling" has occasionally been observed in this project on 1/4-inch-cell "FM-47" bonded panels made with 0.016 inch thick facings. The type of the press padding material, curing pressure, and the adhesive formulation undoubtedly influence the tendency for facings to dimple.

Small-cell cores in the lower density range (3 lbs. per cubic foot, approximately) are somewhat more susceptible to damage from careless handling than are large-cell cores of the same density. Although there is no record of a controlled comparison between small-cell and large-cell cores of the same density, it is possible that light-weight cores in the smallest cell size are susceptible to tearing in the peel test. Peel failures of this type usually occur in conjunction with low failing torques (see Appendix II), but it is not known whether this fact has any design significance.

The first experimental comparisons of the honeycomb materials of various types are presented in Tables 15 and 16 at the end of this discussion. It should be emphasized that these evaluations were exploratory only, and were based on very limited samplings from each type of material. The objective of these evaluations was to determine only if any basic differences in bonding characteristics existed between various types of cores.

Table 15 shows the bond strengths developed by various cores, under the same conditions of adhesive weight. Adhesive weight was kept in a range low enough to confine failures to the vicinity of the core. Although experimentally rolled expanded core was included in this study, standard expanded core, used as a test vehicle in other parts of the project, was not represented. At the time the evaluation was performed it was thought that the results obtained from the use of expanded cores in the "Adhesive Weight" program (Part A, Section I) could be used as a control reference. Later work indicated that two variables, core-prime depth and core cleanliness, were not within the same control ranges when the two sets of evaluations were performed, and that these parameters appeared to be more significant than the independent variable, "type of core material", studied here.

I - E, Continued

Core materials "A" and "B" were made by the corrugation method, by two different firms. Core "A" appeared to have been through a rolling or flattening process which had reduced the height of the sawing irregularities. (An attempt to differentiate between the peel readings in the areas which had received the greatest amount of rolling deflections, and those which had not been touched, was not successful.) Core "A" had a generally clean appearance, but it was not known whether it had been subjected to a cleaning process. Core "B" did not appear to have been rolled or otherwise processed after sawing. The special "rolled-expanded" cores were from an experimental lot which was passed through rollers in an attempt to duplicate the condition of Core "A". Close limits on thickness were obtained by rolling the expanded cores, but the operation produced a compressive buckling or accordion pleating of the cell-walls, rather than merely upsetting the extreme edges, as in the case of corrugated core "A". Apparently, the tears and burrs on the cell-wall edges, on honeycomb which has been bandsawed in an expanded condition, produce stress concentrations which bring about premature local buckling or upsetting at the cell-wall edges, under compressive loading. Core which has been bandsawed before expansion, does not contain local stress concentrations at its edges, and fails in buckling when it is rolled to thickness. Although it did not appear practical to roll cores sawed before expansion, bond strength was observed on this type of material to determine if the different edge configuration might be beneficial.

Core "A" appeared to be superior to core "B" in its ability to provide good bond strengths. Both were superior to the special "rolled-expanded" core in their ability to develop flatwise tensile strength, but were about equivalent in ability to develop peel strength. Later it will be shown that core "A" and standard (not rolled) expanded cores develop very nearly the same peel and flatwise tensile bonds under the same conditions. This fact, in conjunction with the fact that "rolled-expanded" core develops inferior bonds in comparison to core "A", suggests that there is no advantage in rolling core materials merely to upgrade bond strength, as has been done in some instances. Although a greater amount of apparent faying-surface area is presented by a rolled cell-wall edge, the rolled edge presents essentially only one side of the fillet for bonding.

Table 16 shows a number of incidental properties of various cores. The expanded (control) core was included in this evaluation. The rolled-expanded core showed the lowest degree of thickness variation, but its flatwise compressive strength (in panels) was low, probably because of the accordion-pleat buckling induced by the rolling process. Core "B" exhibited a very poor thickness tolerance, but showed excellent compressive strength, even when its high density was taken into account. The cell walls in this core, including the node bonds themselves, were observed to be curvilinear. This curvature apparently lent additional column stabilization to the walls under compressive loading.

I - E, Continued

Taking density into account, corrugated core "A" and expanded (control) core exhibited nearly the same flatwise compressive strengths. Thickness readings on the two cores showed the same order of standard deviation (based on the mean of readings on each sample, not on 0.625 inches), except in the case of one of the "corrugated" samples, which showed one extremely low reading. The area in which the reading was made appeared to have been too low to have been touched by the rolling device used to flatten the asperities. It should be observed that the sampling represented here was inadequate to determine if thickness irregularities of this order might occur in the "expanded" core as well as in core "A".

An experimental core-sizing method developed before the start of the project should be discussed at this point. This method involves the milling of unexpanded slices of rough-cut honeycomb to close tolerances. (A number of special core slices were milled for use in the "curing-pressure" evaluations in this way). The experimental milling device was capable of milling one side in each pass at a feed rate of one lineal foot (equivalent to approximately 10 square feet of expanded surface) per minute, without the use of a lubricant. It appeared that a heavy-duty machine of this type could be constructed which would mill both sides in one pass to obtain an overall thickness tolerance of  $\pm 0.002$  inches. It was felt, however, that the construction of such a machine was not warranted by the demand for flat honeycomb cut to such a close tolerance.

The core delamination observations on Table 16 were made after the cleaning studies in Table 17 were performed. Only core "A" and the expanded cores were tested. (Core "B" was not tested but appeared to be generally low in node-bond strength, as evidenced by local delaminations.) The primary objective of the tests was to determine if node-bond strength was affected by various cleaning methods. Hot inhibited alkaline cleaning alone, or hot chromic acid alone, caused a loss of approximately 10 percent of the original node-bond strength, while the two in combination may cause loss of the order of 25 percent.

In Table 17 at the end of this discussion, the effects of the storage and cleanliness of core material are explored. The top half of the table represents an exposed storage period of four months, after which cleaning was performed on half the specimens, and panels were made from all of them. This work was duplicated on corrugated and expanded cores. The cleaning was done in 165°F solutions of inhibited alkaline cleaner and chromic acid, with rinses after each solution-dip. One panel in each condition was made without a core-prime, and two panels in each condition were made with a light core-prime. The depth of prime on these cores was comparable with that on the panels presented in Table 16, and was less than the depth observed on the panels in the Adhesive Weight program.

I - E, Continued

Cleaning was observed to increase the bond strengths by a significant amount in all cases. The same order of bond strength was displayed by each type of core, under the same conditions of cleaning and storage. This work did not indicate whether the storage was responsible for the low values on the uncleared cores, or whether the strengths were low to start with and were simply increased by the cleaning process. The only available comparison was the preliminary evaluation in Table 15 of core "A", soon after it was received from the supplier. The conditions of the two sets of tests, other than storage and cleaning, were almost identical. When first received, core "A" displayed bond strengths that were much higher than those observed after storage, but comparable with the values observed after cleaning, in Table 17. No realistic comparison could be drawn from other data on expanded cores, so an additional evaluation, shown in the bottom half of Table 17, was run. All cores here were unprimed and were bonded into panels within 24 hours after being expanded. Previous storage in the unexpanded condition was not ascertained.

In the first part of the second evaluation in Table 15, another attempt was made to determine the relative effectiveness of the alkaline and chromic acid treatments, singly and in combination. The comparison of cleaned vs. uncleared cores was unsuccessful in that the two uncleared (control) panels gave widely and unaccountably different bond strengths. The averages of the properties of the two panels were intentionally omitted from the table. The comparison of cleaning methods appeared reasonably valid, however, and suggested that alkaline cleaning alone was the most effective of the three conditions. (Note that the total adhesive weight was low on panels 604 and 605.) It should be noted here that the primary purpose of a chromic acid treatment, subsequent to alkaline cleaning, is to neutralize and stabilize the aluminum surface, and is not necessarily done to develop optimum bond strength. The major significance of the observed effectiveness of alkaline cleaning in this case is that it implies that the surface condition had been downgraded by contamination and not by chemical deterioration. The effects of storage on aluminum cores would undoubtedly be much less severe if the material were kept in the original shipping container.

Since the original purpose of the second evaluation was unfulfilled, a new test was performed, represented by the six panels at the bottom of Table 17. The new results indicated that the cleaning of new core material by the methods used here downgraded bond strength to some extent. The results of this evaluation agreed with the results of the indirect comparison of new and stored samples of core "A", and tended to prove that excessive open storage can cause a deterioration of the faying surfaces of honeycomb cores.

A second conclusion which can be derived from these direct and indirect comparisons is that core "A" and the expanded core yield substantially the same bond strengths under the same conditions of (exposed) storage, cleanliness, and bonding conditions.

Although cleaning of the core could generally be expected to upgrade the facing-to-core bond strength, it should be pointed out that the aqueous cleaning processes used here tended to downgrade the node-bond strength (Table 16). It would appear that cores should be primed or made into panels before any extended open-storage period occurs, to avoid any need for cleaning.

Several other factors should be taken into consideration in the interpretation of these results:

1. The degree of the severity of the control storage used in this evaluation (hanging unprotected in room with hot cleaning solutions) could not be estimated.
2. The light adhesive line and relatively large cell size used in this evaluation caused the bond to be relatively sensitive to adhesion conditions at the surface of the core material.
3. It is generally believed that poor adhesion conditions are conducive to deterioration by corrosion.

The conclusions derived from the work in this phase are as follows:

1. "Corrugated" and "expanded" honeycomb cores made under favorable conditions of manufacture can be expected to yield the same order of bond strength.
2. Honeycomb cores should be primed or bonded into panels before any extended exposure to contamination occurs, if maximum bond strengths are to be realised.
3. The aqueous cleaning of contaminated honeycomb cores tends to upgrade core-to-facing bond strength, but it can also be expected to lower node-bond strength.
4. Some form of rolling or pressing operation appears desirable and practical on flat honeycomb slices that are sawed from corrugated logs or expanded blocks, to improve the thickness tolerance. Such an operation is neither desirable nor necessary on core slices which have been sawed in the unexpanded condition.

TABLE 15  
BOND STRENGTH EXHIBITED BY HONEYCOMBS OF VARIOUS TYPES

Cores: Al 1/4-.003 , 0.580 to 0.625 inches thick. Two samples made by "corrugation" method; one sample of "expanded" material, experimentally rolled to thickness.\* Corrugated samples were used soon after receipt, but previous storage period was not known. Primes were applied in hand-operated roller coater, to shallow depth.

Pacings: Alclad 24S-T3, 0.016" thick, brush primed with TM-47 to 0.002 lbs./sq.ft.

Explanation of Failure Coding:  
 A = Adhesion  
 AC = Adhesion & cohesion mixed  
 C = Cohesion

PART NUMBER	Honeycomb Type	ADHESIVE Thickness M-47 Tape Wt. #/Sq.Ft. (One Side)	Core-Primer # (2 sides) #/Sq.Ft.	Total Cured Wt. (2 sides) #/Sq.Ft.	THREE-INCH PEEL				FLATWISE TENSILE				
					Inch-lb	Average	Percent Failures			Average	Percent Failures (all at core)		
							Facing to tape	Core to tape	A		C	AC	F
239	corrugated from manufacturer "A"	.068	0	.120	42	--	--	--	--	100	375	30	70
240	(sawed edges had been upset by rolling to thickness)	.072	0	.128	50	--	--	--	--	100	386	--	100
263	corrugated from manufacturer "B" (not rolled)	.068	.008	.129	78	1	1	--	--	72	655	100	--
264	corrugated from manufacturer "B" (not rolled)	.067	0	.123	33	--	--	--	--	100	371	--	100
265	corrugated from manufacturer "B" (not rolled)	.075	0	.135	35	--	--	--	--	100	347	--	100
266	ROLLED-EXPANDED*, (Edges Rolled to 0.596" thick from 0.625" thick)	.067	0	.122	44	--	--	--	90	10	270	--	100
265	ROLLED-EXPANDED*, (Edges Rolled to 0.596" thick from 0.625" thick)	.068	.008	.126	91	3	3	18	23	50	458	--	100

\* Expanded core material is not ordinarily rolled to thickness. The slabs tested here were originally procured as standard material, sawed before expansion, then experimentally rolled between serrated nip rolls in three passes. Ordinary expanded honeycomb, used as a test vehicle material in this project, is not represented in this tabulation, and was found elsewhere to be superior to "rolled-expanded" honeycomb in its ability to develop flatwise tensile strength.

TABLE 16

**EXPLORATORY COMPARISON OF  
THICKNESS TOLERANCES, FLATWISE COMPRESSIVE STRENGTHS, AND  
NODE-BOND STRENGTHS OF VARIOUS HONEYCOMBS**

CORE TYPE	THICKNESS TRAVERSES OVER BARE HONEYCOMB (Slices approx. 10"x10"; 12 Micrometer Readings per slice)				FLATWISE COMPRESSIVE STRENGTH (Bonds <sup>a</sup> in panels)				CORE DELAMINATION			
	Panel Avg. Inches	Max. Deviation from average mils	Standard Deviation, mils		Load <sup>b</sup> lb/in.	Core Density, lb./cu. ft.	Average Strength psi	Failure Mode <sup>c</sup>	Pot. of original Strength Retained After Cleaning			
			+	-					Cleaning Methods <sup>d</sup>			
									a	b	a + b	
CORRUGATED from Manufacturer "A"  (Appeared to have been rolled)	.622	3	4	3	239	5.5	708	57	90	93	76	
	.620	2	2	1	240	5.8	676	52				
	.620	3	3	2	263	5.6	758	64				
	.620	2	2	1								
	.618	7	25	8								
	.618	5	2	2								
CORRUGATED from Manufacturer "B"  (No edge treatment)	.570	9	10	6	241	6.5	987	--	--	--	-	
	.589	14	18	12	242	6.4	794					
	.570	9	14	7	264	6.5	998					
	.589	18	12	11								
EXPANDED (Control)	.628	2	1	1	317	5.9	738	124	91	90	86	
	.627	3	2	2	319	5.9	765	135				
	.627	3	4	3	329	6.0	793	130				
	.627	1	1	1								
	.626	1	1	1								
	.626	3	2	2								
ROLLED EXPANDED *** (Approximate initial Thickness: 0.625")	.596	1	2	1	266	5.7	460	--	--	--	--	
	.596	2	2	1	265	5.5	501					
	.596	1	2	1								
	.596	1	1	1								
	.595	1	1	1								
	.596	0	2	1								

\* Specimen dimensions: 5" long, 10" wide, nominally .625" thick.

Test Method: Load applied by rows of pins in tension testing machine.

\*\* Cleaning methods: a: 5 minutes in inhibited alkaline cleaner at 165°F.

b: 10 minutes in chromic acid (7 oz./ 1 gal. approx.) at 165°F.

\*\*\* "Expanded" cores are not ordinarily rolled after sawing. The slices tested here were originally procured as standard material, saved before expansion, then experimentally rolled between serrated nip rolls in three passes.

TABLE 17

EFFECT OF CLEANLINESS OF CORE MATERIAL ON BOND STRENGTHS  
OF PANELS MADE FROM EXPANDED AND CORRUGATED CORES.

**Facings:** Alclad 2BS-T3, 0.016 inch thick,  
cleaned by control methods, and primed  
with uncured "FM-47" to 0.002 lbs/sq.ft.  
**Film:** "FM-47", 0.070 lbs/sq.ft. (avg.).  
**Core:** 1/4-0.003, 0.625" thick ("Corrugated"  
core from manufacturer "A"). Storage,  
cleaning, and coating conditions variable.

Explanation of Failure Coding:  
A = "Adhesion"  
AC = "Adhesion and Cohesion mixed"  
C = "Cohesion"

Test No.	Core Exposure	Core Type	Cleaning Method	ADHESIVE WEIGHTS			TENSILE-INCH PEEL						FLATWISE TENSILE		
				# Primes (2 sides)	# Core-Primes (2 sides)	# Total Coated Wt. (2 sides) #/sq. ft.	Average Inch = #	Low Rdg. P.t. of Avg.	Percent Failed (all tape to core)			Average (six specimens) PSI	Low Rdg. P.t. of Avg.	Failures (at Core)	
				0	0	0			0	AC	A				
542	CORE WITH CLEANING METHODS IN BOILER	Exp.	None	0	.125	35	63	--	45	55		276	89	AC	
543		"	a & b	0	.126	45	56	--	75	85		399	73	C	
541		Cor.	None	0	.127	34	59	--	40	60		302	89	A	
540		"	a & b	0	.126	40	76	--	35	65		380	81	A	
546		Exp.	None	.009	.142	67	66	66	90	10	558	90	C		
545		"	"	.011	.142	66	67	--	90	10	565	558	95	C	
547		"	a & b	.011	.136	71	80	85	90	--	698	94	C		
544		"	"	.011	.137	89	72	72	60	5	658	675	93	C	
536		Cor.	None	.013	.134	63	67	77	--	45	55	531	86	AC	
537		"	"	.013	.135	71	74	--	35	65	525	528	86	AC	
539	CORE PRIMED	"	a & b	.012	.136	90	91	76	--	45	55	609	91	C	
538		"	"	.015	.141	98	71	--	45	55	573	591	85	C	
594			None	0	.128	29	41	--	20	40	338	---	88	AC	
595			"	0	.132	41	--	69	85	--	45	418	95	AC, C	
596			a & b	0	.126	38	40	79	--	50	50	375	79	AC	
597			"	0	.122	30	35	64	--	60	60	363	89	AC	
604			a	0	.112	--	33	--	--	90	10	363	83	C	
605			"	0	.119	33	33	64	--	30	70	403	82	C	
598			b	0	.127	36	34	71	--	45	55	332	80	AC	
599			"	0	.125	33	34	69	--	50	50	315	84	AC	
620		None	0	.128	54	53	53	70	--	85	15	446	90	AC	
621		"	0	.129	59	47	47	69	--	90	10	435	51	AC	
622		"	0	.133	47	--	83	--	85	15	453	86	AC		
623		a & b	0	.126	48	41	41	81	--	85	15	463	87	AC	
624		"	0	.131	39	36	41	72	--	75	25	401	84	AC	
625		"	0	.129	36	35	35	83	--	65	35	392	85	AC	

\* Cleaning methods: a) 5 minutes in inhibited alkaline cleaner at 165°F.

b) 10 minutes in chrome acid (7 oz./gal, approx.) at 165°F.

\*\* Core-primes applied in hand-operated roller coater, to depth of 0.015 inches, approx., air dried.

SECTION I - Continued

F. VARIABLES IN THE PREPARATION OF FACINGS FOR ADHESION

1. Survey Results:

Table 18 at the end of this discussion shows the cleaning cycles used in April 1953 by nine sandwich manufacturers in the preparation of facings for adhesion. It can be seen that there is some difference of opinion among manufacturers in regard to optimum methods and materials in all phases of the cleaning process. The most widely used solution represented here is that originally recommended by Forest Products Laboratory (references 26 and 27), consisting of sodium dichromate and sulfuric acid. Other acid treatments represented in this table are commercial "spot-welding etches," plain chromic acid, and mixtures of chromic acid and sulfuric acid. The last solution is probably equivalent to the sodium dichromate-sulfuric acid solution where the hexavalent chromium contents are the same.

All of these manufacturers used hot, inhibited, alkaline cleaners of some type to degrease the parts prior to acid treatment. Two manufacturers felt that a preliminary vapor degreasing operation was necessary to augment the action of the alkaline cleaner in removing foreign matter from the surfaces of the parts. A hot rinse followed the alkaline treatment in almost every case. There was apparently some difference of opinion among manufacturers as to whether a hot or cold rinse should be used after the acid treatment.

The drying performed after the last rinse was often done in an oven, at temperatures as high as 250°F. Most manufacturers limited the storage or "holding time" between drying and priming to eight hours maximum.

It is generally believed throughout the adhesive bonding industry that nonoptimum cleaning procedures decrease resistance to corrosive or weathering service conditions. This belief has been confirmed in at least two instances.

The following are a number of details that came to light in the survey but are not shown in the tabulation:

- (1) The presence of chloride ion in the acid solution tended to cause corrosion of the facings.
- (2) The disposal of aged, or worn out, acid solution presented a troublesome problem to most manufacturers. In some instances, when these solutions had been dumped down the sewer, damage to conduits and pumping systems had resulted.
- (3) The use of old or deteriorated solutions sometimes caused the facings to be stained or corroded.
- (4) Poor or inconsistent adhesion was sometimes believed to be related to the conditions of alkaline cleaning.

I - F, Continued

2. Preliminary Observations of Cleaning Process Deterioration:

The control cycle for preparing facings for adhesion in this project was chosen from a general study of the tabulated survey results. It was decided that the sheets should be given five minutes' immersion in an air-agitated solution consisting of one part sodium dichromate, 10 parts sulfuric acid, and 30 parts water at a temperature of 140°F. Preliminary to this treatment, a ten-minute immersion in a proprietary, inhibited alkaline cleaner, "OAKITE 61," at 180°F was used. (The choice of alkaline cleaning compounds used in this project was arbitrary and was not based on any knowledge of differences in the suitability of products from various manufacturers.) Later in the project, a change in alkaline cleaning compounds was made from "OAKITE 61" to "OAKITE 61-A", at the suggestion of the manufacturer. A hot (150°F approximately) spray rinse was used after each of these treatments. The sheets were force-dried in warm air for 20 minutes after this cycle, and were primed within approximately one hour. It appeared that these conditions would be generally typical of procedures used by manufacturers.

In the earlier phases of the project no direct evaluations of cleaning variables were made, and it was not anticipated that a major amount of work would have to be done. It will be recalled that in the performance of the "Adhesive Weight" program (Section I, Part A) two chronological periods were observed in which adhesion to the facings appeared to be out of control. Although no exact cause could be assigned to this condition at the time, it was believed to be related to a deterioration in the effectiveness of the cleaning process. This belief was later confirmed. The loss in peel strength was found to have been caused by a relatively minor drop in sulfuric acid concentration, the effect of which had been amplified by a poor selection of process conditions. In order to make this determination it was necessary to go through three stages of investigations of cleaning process variables. In the first stage, the chronological occurrence of peel readings which had showed the loss of control was compared with periodic chemical analyses of the acid solutions. In the second stage, exploratory studies of individual cleaning variables were made. More comprehensive evaluations, utilizing refined methods, were completed in the third stage.

Table 19 shows a consecutive listing of the serial numbers of all panels made in the "Adhesive Weight" program from C-117 through C-205. The peel strengths of these panels have been designated as "low", "medium", or "high" depending on their relationship to the levels of control curves, made when the specimens were broken. The nominal weight of the tape used in each panel is shown in the right-hand column. A number of the "low" panels have been marked with asterisks, indicating that an unusually high percentage of the peel failure was in adhesion to the facing. (These are the same panels which were marked with asterisks in Table 1, and which were left out of the "peel vs. adhesive weight" graphs in Part A of Section I.) It can be seen in Table 19 that the occurrence of low peel

I - F, Continued

readings attributable to poor adhesion at the facing tended to occur during two chronological periods, and that the use of a heavy tape and/or a small cell size tended to bring about an earlier manifestation of the loss of control.

It should be noted that all of the peel strengths which were described qualitatively as "low" in Table 19 would have been considered acceptable under most normal production or design standards. The justification for giving particular attention to these panels lay in the fact that non-optimum cleaning is almost universally considered to make adhesive bonds susceptible to deterioration on exposure to corrosive media.

In order to give an additional chronological representation of peel-strength trends, several panels having two layers of "FM-47" tape under each facing were made with facings which had been cleaned and primed at various times in the project. This type of bond structure promoted conditions which isolated the peel failure at the interface between the adhesive and the facing. Table 20 at the end of this discussion shows the peel results observed in three of these panels. The first of this group, Panel 30, was made from facings which had been cleaned very early in the project, and displayed an unusually high peel strength. (This panel was originally made in order to evaluate the strength developed by a "two tape" system, not to observe the degree of adhesion at the facings.) Panel 151 was made at the time that the first series of unaccountably low peel readings was observed. Its unusually low peel strength supported the conclusion that the cleaning or priming processes had gone out of control. As an additional check, a facing which had been cleaned during the first suspected periods of deterioration, and one cleaned in a relatively new solution, were bonded into Panel 187. The significant difference in peel strengths developed in the two sides of this panel confirmed that the cleaning and/or priming processes had gone out of control.

In the course of the work, samples of the acid cleaning solution had been analyzed periodically as a routine check, which could be used as an aid in isolating the cause of unforeseen deterioration factors of the type involved here. Table 21, at the end of this discussion, shows these analyses, and shows the serial numbers of the panels made at the time the samples were taken. The analyses corresponding to panels C-154 and C-200 represent the conditions in the acid solution during the two periods in which control had been lost. Although the concentrations of some of the individual solution components appeared to have been affected by age and/or usage of the solution in the two analyses in question, a comparison with the chronological trends of peel strength in Tables 19 and 20 did not reveal any obvious correlations between individual process factors and peel strength. (Later work proved that reductions in acid concentrations had been at fault, but these reductions did not appear significant at the time the comparison was made.) It was decided that additional efforts should be made to isolate the exact cause of the deteriorations.

3. Exploratory Studies of Cleaning-Process Variables:

Before undertaking the isolation of the factor responsible for the loss of control over peel strength, it was felt necessary to determine how adhesion could be most effectively determined quantitatively. In general, the results of the "Adhesive Weight" program (Section I, Part A) had indicated that flatwise tensile strengths were not affected by adhesion conditions at the facing. Since it was hoped that the isolation program could be conducted through the use of only one physical test, a program was initiated to positively determine if, under very unfavorable conditions, flatwise tensile strength might be affected by adhesion at the facing. It was felt that unclean facings represented the most unfavorable conditions for adhesion. Four panels were made with unclean facings bonded to the core under typical adhesive weight conditions, and were broken in peel and flatwise tensile tests, the results of which are shown in Table 22, at the end of this discussion. While the peel strengths had dropped to low values, flatwise tensile strength remained at a level which was normal, or slightly above normal. (It should be observed that no flatwise tensile failures were observed to have occurred between the tape and the facing in the entire project, other than in cases where no pressure had been applied during bonding.)

Since it appeared that flatwise tensile strength was not quantitatively related to adhesion conditions at the facing, it was decided to conduct peel tests only, and to conduct these tests on panels which had been made with special, heavy bonds consisting of three "FM-47" tapes. The purpose in using multiple tapes was to provide adhesive-to-core bonds which were strong enough to assure that the peel failure occurred at the interface between the adhesive and the facing. It was also decided that all of the "three-tape" panels should be made with a high-density core material in a small cell size (1/8-.002), to assure that peel failures would not occur in the core material, and that the value would be a true measure of adhesion at the facing.

Table 23, at the end of this discussion, shows the results of a number of exploratory evaluations which were intended to isolate the cause of critical factors in the cleaning process. It is important to note that the majority of facings were cleaned under the standard control conditions used in the earlier phases of the project. Some of the last exploratory evaluations indicated that these control conditions might be in a critical range. In view of the fact that the choice of temperature (140°F) and immersion time (5 minutes) in the acid solution did not assure that ultimate values of adhesion were obtained, the exploratory evaluations of most of the other variables appeared inconclusive. It should be noted, however, that the control conditions used here were consistent with the general practice of the adhesive-bonding industry, and that ample justification for their choice existed in the survey data. Later work proved that the effects of time and temperature must be considered if conclusive evaluations of individual cleaning solutions are to be made.

I - F, Continued

Since individual comments and conclusions have been presented along with the quantitative results of the exploratory evaluations in Table 23, a detailed discussion will not be made here. The following general conclusions were made from the results:

- (1) Variables in the alkaline cleaning process had little effect on adhesion.
- (2) The addition of intentional contaminants such as trivalent chromium, chloride, and ferric ion did not have significant effects on the level of adhesion.
- (3) A preliminary wipe with chlorinated solvent before the alkaline treatment appeared to downgrade adhesion.
- (4) The concentrations of sodium dichromate and sulfuric acid had some effect, but the nature of this effect was not clearly represented.
- (5) Acid temperature was probably not held within the limits of control required by the particular conditions of the above evaluations.

It was decided at this point that the effects of individual process variables could not be resolved by the conventional type of evaluation utilizing only one immersion time and temperature, and that surveys of literature dealing with research methods used on other types of cleaning processes should be initiated to determine if more refined methods might be available. It was further decided that before more work was initiated, the basic control variables should be evaluated to determine the ranges in which they were critical.

A considerable amount of experimental data relating to the chemical preparation of clad, heat-treated, aluminum alloys for spot welding was found in past issues of the "Welding Journal". (A bibliography of these references is included in this report, following the bibliography of sandwich-bonding references.) The type of cleaning process investigated here appeared to be analogous to the processes used in the preparation of aluminum for adhesion. It should be noted at this point that Firm "C" in Table 18 used a commercial room-temperature spot-welding preparation in lieu of the standard hot sulfuric acid-sodium dichromate solution. "Etches" of this type are usually based on a combination of hexavalent chromium ion and an inhibited type of hydrofluoric acid, and are used subsequent to an alkaline degrease and hot rinse. They are not true "etches" in that they do not remove a significant amount of material from the sheets, but only deoxidize the surfaces, bringing the electrical contact resistance at the surface to a low value, of the order of 10 micro-ohms.

I - F, Continued

The background of research on spot-welding preparations included comprehensive evaluations of the effectiveness of the process as a function of concentrations, alkaline degreasing methods, rinsing and drying cycles, holding time, immersion times, and solution temperatures. It appeared that much of this information would be directly or indirectly applicable to the preparation of aluminum for adhesive bonding.

In the spot-welding research, electrical surface-resistance measurements were used to evaluate the effectiveness of the treatment. One of the principle objectives was to establish a non-critical process in which consistently low surface resistance could be maintained. In each experiment, resistance measurements were made on a large number of coupons immersed for various lengths of time in the test solution. As changes were made in the process conditions, the lowest observed values of surface resistance did not vary appreciably, but the optimum immersion time required to bring about a low resistance was subject to wide variations. If all of the resistance measurements had been made at a constant acid-immersion time, the results would have had little significance. It was decided that future evaluations of adhesion as a function of chemical surface treatment variables should be based on "peel strength vs. acid immersion time" curves, rather than of measurements of peel strength at constant immersion time. This change was later found to be amply justified.

It was also decided that measurements of electrical surface resistance could be made in the course of the work at hand, to determine if there might be a useful relationship between surface resistance and the degree of chemical preparation for adhesion.

4. Rinse Temperature and Holding Time:

Before the "peel vs. acid immersion time" program was initiated the effects of rinsing temperature and of storage or "holding time" between cleaning and priming were determined. The reported results of the research on spot welding treatments had shown that high rinsing temperatures, long rinsing times, and high alkalinity of the rinse water downgraded the effectiveness of processes of this type. It should be noted that the water used for rinsing the cleaned facings in this project was in a relatively high range of pH (8.5 to 9), and that the effect of rinse water on adhesion was not evaluated. The survey results had indicated that there was a difference of opinion among manufacturers as to whether the rinse subsequent to acid treatment should be hot or cold. The survey results also indicated that most manufacturers considered long holding times to be detrimental to adhesion.

Table 25 shows the results of two studies in which "holding time" was adjusted. In the first study a hot rinse was used on all of the facings, in accordance with the original control procedures. After cleaning, the facings were suspended from hooks in a shop area for from 20 to 100 days. Panels which had been made from facings stored in this manner for 20 days showed peel values ranging from 221 inch-lbs., the usual maximum which can be realized where 0.016-inch alclad 248-T3 facings are bonded with "FM-47", to as low as 129 inch-lbs., a level which was considered "out of control". A second set of facings, made into panels after 100 days of exposure, showed peel strengths ranging from 54 to 111 inch-lbs., indicating that an exposure of this duration could not be tolerated.

The second evaluation shown on Table 25 was conducted on two groups of cleaned facings, corresponding to rinse temperatures of 70°F and 150°F, approximately. Holding times were adjusted from five minutes to one week, in order to allow storage effects to be observed within a more reasonable range of conditions than were held in the previous evaluation. The cold rinse upgraded the peel strengths developed by these facings by approximately five percent. Holding times of the order of one week did not appear to affect peel strengths. It should be noted that the type of exposure used in the second group was different from that used in the earlier group in which 20-day and 100-day exposures were imposed. The second group was suspended in the same room in which the facings had been cleaned, whereas the first group had been exposed in a shop area. It was not known which of these two conditions was more unfavorable.

Although the results of the work represented in Table 25 were undoubtedly influenced by the exact nature of the exposure conditions, it appeared that the maximum holding time of four hours imposed in most process specifications was conservative, as long as reasonable precautions were observed to prevent the stored parts from being contaminated. It was further decided that the control conditions within this project should be revised to use a cold rinse rather than a hot rinse subsequent to acid treatment.

I - F, Continued

5. Evaluations of Cleaning-Process Variables in Terms of  
Peel Strength vs. Acid-Immersion Time:

A series of evaluations of cleaning process variables in which acid-immersion time was made the independent variable are shown in Table 24. It was decided to perform the studies at two acid temperatures; 140°F and 160°F. The control facings in the program were alclad 24S-T3, 0.016 inches thick. The facings cleaned at each of the immersion times were primed and bonded with three layers of "FM-47" tape to nine-inch-square slices of al 1/8-.002 core material 0.625 inches thick. Two three-inch-wide peel specimens were tested from each of these panels. The percentage of the facing area which appeared to have failed in adhesion was observed and recorded on each specimen. The acid solution was analyzed periodically in the course of the investigations.

In the course of these investigations, a commercial "surface resistance analyzer" of the type used in resistance welding quality control work was used to take readings on the freshly cleaned and dried sheets, to determine if electrical surface resistance might exhibit a correlation with peel strength.

Group C, in Table 24, represents the first "peel vs. immersion time" series, which was to have been used as a control. Before the fabrication of these panels was completed, it was noted that the facings did not appear to have been thoroughly degreased by the alkaline treatment. This group (Group "C") was set aside, and was later compared with new sets of control panels, made after the alkaline cleaning conditions were improved.

Groups "A" and "B" represent the control panels made after the adjustment in alkaline cleaning solution conditions. The peel strengths observed in Groups A and B were plotted in Figure 35, and were assumed to represent the control relationship between peel strength and immersion time at two temperatures, other conditions of the process being optimum. Later, Groups "O," "P," and "V," which were made under near-optimum conditions, were added to the control curves to augment them. The shapes of the two control curves in Figure 35, corresponding to the two acid temperatures, are entirely different. It can be seen that the original control conditions used in earlier evaluations (five minutes' immersion at 140°F) were in a region of the curve which was sloped, suggesting that these conditions might have been too critical in themselves to permit the effects of other variables to be defined. At an acid temperature of 160°F, it appeared that an immersion time of the order of three minutes would allow a maximum level of adhesion to be consistently realized, while at least eight minutes would be required to maintain consistently high peel at an acid temperature of 140°F. Both curves reached the same maximum level of approximately 200 inch-lbs. It was observed that unusually long immersion times sometimes brought about a loss in peel strength, particularly where a high temperature was used.

I - F, Continued

Figure 36 shows the peel strengths observed in the panels which were originally to have been used as a control, but which showed evidence of having received inadequate alkaline cleaning. Although the position of the curve was shifted laterally, in the lower range of acid-immersion times, it appeared that maximum adhesion was not affected by the presence of the residual deposit from the alkaline cleaning process.

The survey of research on spot-welding alclad 24S-T aluminum had indicated that the thickness of the sheets was an important parameter in determining the "surface resistance vs. immersion time" characteristics associated with spot-welding preparations. Thin sheets required much shorter immersion times than did 0.040 inch-thick sheets. Figures 37 and 38 show the "peel strength vs. acid-immersion time" relationships at acid temperatures of 140° and 160°F, using alclad 24S-T3 sheets 0.032 and 0.012-inch thick. A comparison of the shapes of these curves with the shapes of the control curves in Figure 35 indicates that sheet thickness has the same effect in the preparation of facings for adhesion as it does where sheets are prepared for spot-welding. Although facings that were 0.032-inch thick required only slightly longer immersion times than did facings which were 0.016-inch thick, there was a considerable difference in the optimum immersion times required for 0.012-inch and 0.016-inch thick facings.

The shorter acid-treatment immersion-times required for thinner sheets are probably attributable to the fact that copper from the "core" alloy has migrated through the thin layer of relatively pure outer cladding material during the heat-treating process, making the outer surfaces more reactive. (This characteristic is also believed to make thin sheets less resistant to corrosion.) Another factor that may contribute to the sensitivity of acid-treatment conditions to sheet thickness is the probable reduction in oxide film thickness as successive rolling passes are made. Thin sheets would have correspondingly thinner films of oxide, which would require less time for removal.

It may be seen in Figures 37 and 38 that the 0.032-inch facings developed higher maximum peeling torques than did the 0.012-inch facings. Had one of the thicknesses exhibited higher percentages of adhesive failure than the other, it would be suspected that its surface was less suited, chemically, for the development of high bond strengths. A comparison of these percentages in Table 24 is inconclusive, however. The comparison of peel torques developed by the two thicknesses does not necessarily prove that one or the other surface is superior, since there is undoubtedly a difference in the amount of torque required to bend the facings of each thickness. In a drum-type peel test, without back-loading, the torque required to bend the facings is influenced by the adhesive forces in the bond, since these forces determine the radius of curvature of the metal at the line of failure. If sufficient back-loading were applied to the specimen to draw the facing snugly against the drum, the adhesive forces would not influence the amount of torque required to bend the facing, but this torque would still be a function of the thickness, the elastic modulus, and the yield strength of the metal. The complicated interrelation

I - F, Continued

of adhesive forces and bending forces in the peel test without back-loading makes it impractical to experimentally isolate the effects of facing alloy or thickness on the individual magnitudes of either type of force. The use of a back-load, sufficient to hold the facings against the drum would remove the effects of adhesive forces on the torque required to bend the metal but the energy absorbed by the metal would still be a function of thickness. Experience in this project has indicated that the drum test without backloading is generally satisfactory for the purpose for which it is intended, i.e. to establish comparisons of bond strengths where facing material or thickness are not variables.

Figure 39 shows the peel strength vs. acid immersion time characteristics of alclad 75S-T6 alloy, 0.032 inches thick, at an acid temperature of 140°F. (It should be noted that the cladding material used in this alloy is of a different composition from that used on the 24S alloy.) The 0.032-inch material evaluated here was almost identical with 0.016-inch alclad 24S-T3 in its acid-treatment characteristic. A curve representing alclad 24S-T3 0.032 inches thick has been traced from Figure 38 on this graph. It appeared that alclad 75S did not develop the same order of adhesion observed on alclad 24S sheet of the same thickness. Since the yield strengths of the two metals are substantially different, the amount of peeling torque absorbed in bending the facings must also be different. Peel-strength readings, therefore, do make absolute comparisons of the adhesive forces developed on each type of surface.

In Figure 40, the peel vs. immersion-time characteristics are shown for three groups of facings which were acid-treated without the use of air agitation. The consecutive points in each series have been connected by straight lines to show their wide degree of dispersion. The erratic nature of these peel curves was probably the result of local temperature variations in the solution, resulting from the lack of agitation.

Figure 41 shows the peel vs. immersion-time characteristics for three groups of facings cleaned in acid solutions that had received considerable use. The individual points on these curves show an unusually high degree of dispersion. (It should be noted that these groups were run at an acid temperature of 160°F only.) It can be concluded that inconsistent results (not necessarily low readings only) might be expected where acid solutions have received extended use, which points up the necessity for frequent chemical analysis.

Some facings that had received long acid-immersion in the "worn" solutions showed the presence of a grey-white scale. It could not be determined whether this scale extended inward or outward from the original plane of the surface of the sheet. Micrometer readings did not indicate any difference in thickness which could be attributed to the deposit. In priming the surfaces of some of the heavily-scaled sheets, it was observed that the liquid tended to be absorbed within the scale. Although the peel strengths developed by heavily scaled surfaces did not appear to be unusually low, it was believed likely that eventual resistance of the bonds to weathering and corrosion attack would be impaired. No attempt was made to determine if the structural properties of the metal had been impaired by the presence of the scale. Since the scale observed

I - F, Continued

on these sheets might be very likely to occur under normal production conditions, it was decided that further work should be done later in an attempt to isolate the cause of the condition.

Figure 42 shows the effect of "breaking-in" the acid solution. Spot-welding literature had indicated that freshly prepared acid solutions did not show optimum characteristics, and that the optimum characteristics were not developed until a significant amount of material had been processed, or until aluminum salts were added to "catalyze" the solution. The exploratory evaluations had previously indicated that the same characteristics might be true for the hot sulfuric acid-sodium dichromate solution, since the use of a fresh solution appeared to have brought about low peel strengths in one case. Group "O" in Figure 42 was processed directly after a fresh acid solution had been mixed. Group "P" was processed after several racks of facings had gone through the original fresh solution. There was no detectable change in "peel strength vs. immersion time" characteristics as a result of breaking in the solution. Both groups showed very little dispersion about the control curve.

Figures 43 and 44 show the effects of sulfuric acid concentration on a typical solution at two acid temperatures. At the acid temperature of 160°F (Figure 44) the concentration of the acid showed no effect. Where an acid temperature of 140°F was used, however, acid concentration appeared to have a very striking effect on the peel strength vs. immersion time characteristics of the solution. Where the acid concentration was low, a longer immersion schedule was required to obtain optimum adhesion to the facings. The normal concentration was 22.4 percent, whereas the "low" acid concentration used here was 16 percent. This concentration was of the same order as the concentration observed during both of the periods of suspected cleaning-process deterioration. (see Table 21). It was concluded that a depletion in acid concentration brought about by chemical usage, and/or "drag out" was the cause of the low peel strengths observed in the "Adhesive Weight" program.

Before leaving the discussion of Figures 43 and 44, it should be noted that another apparent deterioration of the alkaline cleaning process was observed in the "high acid" series (Figure 43) run at 140°F. This series was the last one run in the program. Residual deposits remained on three of the facings which received the shortest immersion times and the pattern of the stenciled lettering was in evidence in the deposit. The shape of this curve is generally similar to that observed in Figure 36, where inadequate alkaline cleaning was also in evidence. The inadequacy of the alkaline cleaning process in these two instances was not attributable to the type of cleaner, but was a result of over-use and/or improper maintenance of the conditions of use.

It can be seen in Table 24 that measurements of surface resistance showed no apparent correlation with peel strength in the majority of the groups on which readings had been taken. A definite correlation between surface resistance and peel strength was later observed where a commercial spot-welding treatment had been substituted for the sulfuric acid-sodium dichromate process.

I - F, Continued

Figures 45 through 48 show the effect of the concentration of "active" sodium dichromate on the "peel strength vs. immersion time" characteristics. A significant amount of trivalent chromium was placed in these solutions to simulate the effect of depletion of the active hexavalent chromium from extended use. These curves indicated that sodium dichromate had an inhibiting effect on the action of the solution. Where no active sodium dichromate was present, very low peel strengths were observed in the normal range of immersion times. (It is possible that a relatively high peel strength could have been obtained at a very short immersion time, but this was not considered a practical condition.) The time required to reach a suitable maximum level of adhesion was increased as the concentration of active sodium dichromate was increased from 0.1 part to 4 parts. (A concentration of one part is normally recommended for the hot sulfuric acid-sodium dichromate solution, where 10 parts of sulfuric acid and 30 parts water are used.) Where strip aluminum would be processed continuously in a long acid tank, the effect of sodium dichromate concentration might be very important.

The curves in Figures 45 through 48 indicate that the level of maximum adhesion increased from approximately 180 inch-lbs. to approximately 210 inch-lbs., as the concentration of sodium dichromate was increased from 0.1 part to 4 parts. Since this trend was not observed in other parts of the program where the concentration of sodium dichromate had been varied, no firm conclusion was made. It was felt that minor variations in the level of maximum adhesion were of less importance than the ability to consistently develop peel strengths in a non-critical maximum range. It should be noted that the effect of sodium dichromate concentration was evaluated at only one acid temperature, 160°F, and that this temperature is the upper limit on the normal range of temperature at which the solution is used.

The following general conclusions can be drawn from the evaluations of peel strength in which acid-immersion time was the independent variable:

(1) Acid temperature has a very striking effect on the peel vs. immersion time characteristics of clad aluminum facings treated in the sulfuric acid-sodium dichromate solution. The temperature has little or no effect on the maximum level of adhesion obtained.

(2) The concentration of sulfuric acid in the solution determines its "peel vs. immersion time" characteristics at acid temperatures of the order of 140°F, but has little effect at an acid temperature of 160°F.

(3) An increase in the concentration of sodium dichromate causes the solution to be slower in its operation.

(4) Thinner sheets require less time in the solution for optimum adhesion to be attained.

I - F, Continued

(5) There is little apparent difference between the immersion-time characteristics of alclad 248-T3 and alclad 758-T6, but there is a difference in the apparent level of adhesion which can be developed on the surfaces of these two alloys in a given sheet thickness.

(6) The apparent magnitude of adhesion as measured in the "four-inch-drum" peel test is influenced by the thickness and alloy of the facing material. The amount of torque required to bend the facings is itself a function of adhesion, since the radius of curvature of the bend is influenced by bond strength. While the use of a "back-load" to hold the facing positively against the drum undoubtedly removes the tendency for the adhesive forces to influence the amount of torque required to bend the facings, this component of torque is still a function of gage. A drum-type test without back-loading gives satisfactory comparisons of bond strengths, where facing material and thickness are not variables.

(7) Acid solutions which have received considerable use tend to give erratic values of adhesion and can also cause pitting or scaling on the surfaces of the sheets which have been processed at long times and/or high acid temperatures.

(8) Some form of agitation or forced convection should be used to assure that temperature is consistent throughout the acid solution.

(9) Freshly prepared solutions of hot (160°F) sulfuric acid-sodium dichromate solutions do not require special immersion schedules. New solutions give consistently good results.

(10) Alkaline cleaners which have been used to excess may leave deposits on the surfaces of the facings which are retained throughout the acid treatment. Peel strengths, in the optimum range of acid-immersion times, are not downgraded by this condition.

## 6. Studies of the Causes of Appearance Defects on Facings:

A special series of tests was initiated in an attempt to isolate the cause of the formation of the scale observed in connection with the use of old or deteriorated acid solutions. It was thought that the cause of this scaling was in the form of a contaminant, introduced either as a product of the reaction at the surface of the sheets; as a suspended material in the compressed air used for agitation; or as a product from the corrosion attack on the stainless steel tank. Peel strengths were not observed in these tests, since earlier work had indicated that peel strength was not always seriously downgraded by the presence of the scale. Small rectangular coupons, one inch wide and two inches long, of alclad 24S-T3 in various thicknesses, were immersed in agitated test solutions at 160°F, and were removed at one-minute intervals in a range from zero to 25 minutes of total immersion time. All the coupons were given a preliminary hot alkaline treatment and hot rinse before the acid treatment. On removal from the acid solution, the coupons were immediately rinsed under a cold water spray for approximately 15 seconds. After being dried in warm air, the coupons were carefully affixed to large sheets of blotting paper in increasing order of immersion times. The appearances of the surfaces of the coupons in the various groups were then compared.

A control was first established, using the deteriorated solution represented by group "S" (Figure 40). Groups of coupons were run in thicknesses of 0.008, 0.012, 0.016, and 0.032 inch. The characteristic scale began to form on these coupons at approximately 6 minutes. Thinner sheets showed relatively heavier deposits, and the formation of these deposits occurred in a shorter time. An attempt was made to photograph these specimens, but the results were not satisfactory. The scale appeared to have a striated appearance, in the rolling direction. While some of the coupons displayed a yellowish tint, the scale was ordinarily a grayish-white in color.

The analysis of the control (deteriorated) solution shown in Table 24, (Group "S") indicated that the hexavalent chromium content was very low, and that the iron content was not unusually high. Chloride and silicon were not present in excess, but the content of aluminum was relatively high. It was decided to make up test solutions in which these and other concentration conditions were artificially induced. Thirty additional series of coupons were run in various thicknesses, in various artificially-controlled solutions. A tabulation of these results was not attempted, but the following conclusions were drawn from the study:

(1) Excesses of trivalent chromium (up to three "parts") did not tend to produce the scale in question. The coupons cleaned in solutions which were high in trivalent chromium content often showed "rinsing stains," however, indicating that the salts in this solution were less soluble.

(2) Chloride concentrations of 500 parts per million caused severe pitting and corrosive attack of the coupons at immersion times in excess of 10 minutes on the thinner sheets. Chloride concentrations of 50 parts per million caused no noticeable attack at immersion time as high as 20 minutes. The type of whitish scale which was under investigation was not produced by chlorides.

I - F, Continued

(3) A ferric ion concentration of 0.4 percent did not bring about the scaling action in question.

(4) Agitation of the solution tended to accelerate the formation of the scale, suggesting that the offending contaminant might be suspended rather than dissolved in the solution. Mechanical agitation appeared to be as effective as air agitation in accelerating the formation of the deposit.

(5) Low concentrations of active sodium dichromate in themselves did not produce the white scale.

(6) Additions of aluminum hydroxide, which brought the calculated concentration of aluminum ion to 0.5 percent, did not bring on the appearance of a scale. (An analysis of this solution revealed only 0.23 percent aluminum. Periodic analyses of other solutions used in the course of the project indicated that a maximum of 0.3 percent of aluminum could be detected by analysis of the dissolved components.)

(7) Although the action of an acid solution in good condition tended to dull and whiten the original finish of the aluminum to a certain extent, emphasizing the appearance of the rolling marks, there was normally no "etching" effect, and the surfaces retained a high degree of reflectivity.

(8) When the original deteriorated solution used as a control was rejuvenated to the normal recommended sodium dichromate concentration, the formation of the scale ceased, and was replaced by a pitting action. The pits formed here were randomly distributed over the coupons, but appeared to be more concentrated near their centers. The first traces of pitting were observed at an immersion time of six minutes on 0.012-inch material. At an immersion time of 25 minutes, the pitting was strongly in evidence, and some of the pits appeared to be as large as 1/64 inches in diameter. The pits were not black, as were those produced by chloride contamination, but were whitish in appearance. The remainder of the surface of the sheets did not show any unusual discoloration.

(9) When the deteriorated solution which previously had been rejuvenated to its normal sodium dichromate concentration was brought to its normal level of acid concentration, the pitting action became more severe.

(10) When a fresh charge of alkaline cleaning solution ("OAKITE 61-A") was mixed, the pitting action observed in the rejuvenated deteriorated acid solution was not inhibited in any way. It was not determined whether the drag-out of silicate compounds from the alkaline cleaner might have been responsible for the scale. As far as is known all alkaline cleaning compounds contain silicates.

It was concluded that no satisfactory determination had been made of the cause of the scaling actions associated with the use of "worn-out" or deteriorated acid solutions at relatively high temperatures and long immersion times. The rejuvenation of these solutions to their normal recommended concentrations removed the tendency to form the scale, but replaced it with a pitting of the surfaces, which was even more undesirable. Chloride

I - F, Continued

concentrations of the order of 500 parts per million had an obvious destructive effect in themselves, but were not responsible for the formation of the particular scale under study. The concentrations of iron, aluminum, and trivalent chromium in the solutions did not appear to be responsible for the scale. It was definitely established that the thinner clad materials were more susceptible to the formation of scale, or to corrosive attack. The likelihood of the occurrence of these undesirable conditions under ordinary production procedures might in some instances call for the selective use of immersion schedules on various sheet thicknesses and/or the frequent replacement of acid solutions.

It is possible that the appearance defects observed here may be related in some way to impurities in the local tap water, or to some other factor that was not studied in these tests.

Although no accurate usage data were available, because of the variable nature of the times and temperatures used in the project, it was estimated that approximately 300 square feet of facings had to be processed in the ten-gallon tank before the scale deposit began to appear on the surfaces. It is probable, however, that the conditions of the tests and the small size of the tank caused this square-footage figure to be pessimistic with respect to normal production conditions. Assuming that in normal production 60 square feet of facings could be safely processed with each gallon of acid solution, in a 3000-gallon tank the chemical cost per square foot could be determined in the following manner:

Total weight of solution at 10 lbs/gal: 30,000 lbs.

Weight of sulfuric acid (@3.7¢/lb.) assuming additional "upkeep" added to original charge: 8,000 lbs.

Weight of sodium dichromate @ 17¢/lb.

(Note: Cost surveys indicated that sodium dichromate is cheaper than chromic acid in terms of hexavalent chromium content. Assumes that original charge and upkeep total 4 parts.)

Total cost of charge

$$= (3.7) (8000) + 17 (2700) = \$300 + \$450 = \$750.00$$

Cost per square foot of facings (half of cost per sq. ft. of sandwich), assuming 60 sq. ft. can be processed with every gallon:

$$\frac{\$750.00}{3000 \text{ gal} \times 60 \text{ sq. ft./gal.}} = \underline{0.4¢/\text{sq. ft.}}$$

This cost does not include the mixing labor or the costs of disposing of the spent solutions. The percentages of the total cost of processing facings which this figure represents would be very small for existing batch operations, but would be significant in a continuous coil-processing line.

I - F, Continued

The useful life of the acid cleaning solution may be extended in the following ways:

(a) By using lower acid temperatures and/or short immersion times. This practice calls for more careful selection and control of acid temperature, immersion time, and chemical concentrations.

(b) By using distilled water or boiler-feed water in making up the original charge. It is not definitely known whether this practice will reduce the tendency to produce scale; it would be mandatory where the chloride content of the water exceeded 50 ppm. Distilled water usually costs from two to five cents per gallon.

(c) Possibly by the use of "ion exchange resins" to remove solution contaminants. (These compounds were not evaluated.)

#### 7. Exploratory Evaluations of Miscellaneous Cleaning Methods:

The results of several exploratory evaluations of "non-standard" methods for preparing aluminum surfaces for adhesion are shown in Table 26. These evaluations were performed entirely with 0.016 inch thick facings of alclad 24S-T3, bonded with three "FM-47" tapes to al 1/8-.002 core. Measurements of electrical surface resistance were made on some of these facings just before the priming was performed.

Particular attention was given to a "room-temperature", proprietary, spot-welding etch, "DIVERSEY 514", since it appeared desirable to determine if a correlation between the techniques used in preparing aluminum surfaces for adhesion and for spot-welding might exist. This particular compound was chosen for evaluation because it had been used by one airframe manufacturer in preparing surfaces for adhesion. It is probable that most compounds of this type are similar in composition, and that all are basically similar to the materials developed under the research projects covered in the spot-welding bibliography.

Since it was known that the operation of spot-welding preparations is adversely affected by the presence of ferric ion, the evaluations were duplicated in a "PYREX" vessel and in the tank of "CARPENTER'S Stainless No. 20" steel which was ordinarily used to contain the hot acid solution. Facings were treated in the tank at room temperature and at 110°F. Although these solutions are seldom used at temperatures above 80°F, it appeared desirable to determine if an accelerated reaction could be induced by heat, in order to be able to economically process continuous webs.

I - F, Continued

The graphical results in Figure 49 indicate that the spot-welding preparation is capable of producing the same maximum degree of adhesion as is produced by the conventional hot sulfuric acid-sodium dichromate solution but that the conditions of its use are more critical. The presence of ferrous materials appeared to reduce the effectiveness of the solution. A warm solution appeared to be far too critical in its peel vs. immersion time characteristics to be practical, while the room-temperature cycle was more critical than the conventional hot sulfuric acid-sodium dichromate solution, in this respect. No tests were performed to determine whether treatment of the facings with the spot-welding preparation resulted in bonds which were fully resistant to deterioration from exposure.

The tabulated results (Table 26) indicated that surface resistance readings showed some correlation with peel strengths when the spot-welding solution was used. Very low values of surface resistance produced maximum peel strengths, except in the series in which the solution was warmed to 110°F. It should be re-emphasized at this point that the conventional, hot sulfuric acid-sodium dichromate treatment does not produce a correlation between surface resistance and adhesion, nor is it suitable for use in treating aluminum to reduce its surface resistance. It is superior, however, to at least one (and probably all) spot-welding solutions in its ability to develop optimum adhesion. It might be possible to chemically modify the room-temperature spot-welding preparations to give equivalent results. Such a development would be desirable in that the requirements for corrosion-resistant equipment would be much less demanding, and in that there would be no need to heat the solutions. A revised type of spot-welding treatment for developing adhesion might also lend itself to quality control by means of surface-resistance measurements.

Two other acidic treatments, which were evaluated for presentation in Table 26, were 25 percent sulfuric acid and 5 percent chromic acid. Sulfuric acid, at this concentration and temperature, was entirely unsuitable. (This conclusion is based partly on other findings; see Figure 45.) No conclusions may be drawn in regard to the suitability of chromic acid as a post-alkaline treatment, since it has been proved that an evaluation based on one concentration, one temperature, and one immersion time is inconclusive.

Of the three degreasing methods, evaluated without subsequent acid treatment, alkaline cleaning gave the best and most consistent results. "Vapor degreasing" was not evaluated, but would probably have given better results than did the "wipe" with a chlorinated solvent.

8. Degreasing Preliminary to the Acid Treatment:

Although no comprehensive evaluation of variables associated with the preliminary degreasing treatment was performed, several general observations can be made:

(1) Commercial alkaline cleaning preparations are entirely suitable for removing dirt, oils, and stenciled lettering from the surfaces of the sheets, prior to acid treatment, as long as the solutions are "kept up" and replaced often enough to maintain their effectiveness. Alkaline treatment alone does not prepare facings satisfactorily for adhesion.

(2) The possibility that "drag-out" from the alkaline solutions may have contributed to the deterioration of the acid cleaning process was not explored.

(3) Ordinary recommended titration methods, used in the project, did not reveal the fact that alkaline cleaners which had been used to excess were not functioning correctly. ("Double titration" methods may be of value in determining the effectiveness of some types of compounds.)

(4) Published information on alkaline cleaning compounds indicated that the warm or cold rinse subsequent to alkaline cleaning should be performed as soon as possible to prevent the cleaning compounds from drying on the sheet surfaces.

(5) A considerable number of proprietary, inhibited, alkaline cleaners are on the market, and the optimum conditions of use for each type should be obtained from the manufacturer. (Some general evaluation work on cleaners of this type is contained in literature on spot-welding research.)

(6) Vapor degreasing with chlorinated hydrocarbons was not evaluated in this project, but it is probable that this type of cleaning would not remove stenciled letters from cut-sheet stock, unless some means such as "ultrasonic agitation" were available to augment it. Ultrasonic agitation is difficult to apply over the surfaces of large sheets. It is probable, however, that an ultrasonic unit could be incorporated in a continuous coil-processing line, in conjunction with a vapor degreasing system.

(7) It appears that "spray" alkaline cleaning would be the most practical means of removing dirt and oils from coil stock, on a continuous basis. Spray alkaline cleaners represent a special class of compounds which are "non-foaming", and are used at relatively low concentrations.

(8) A generally accepted theory in the technology of alkaline cleaning is that the silicate which is used in all "inhibited" aluminum cleaners to prevent etching or "gassing" forms a protective surface film of colloidal aluminum silicate. This film tightly adheres to the surfaces of the sheets through the subsequent hot-rinsing operation and prevents the formation of additional oxides. Were it not for the film of silicate, aluminum would be attacked by any hot aqueous solution having a pH in excess of 8. It is interesting to note that silicates are considered to be insoluble in both sulfuric acid and chromic acid.

I - F, Continued

9. Other Variables Associated with the Preparation of Aluminum for Adhesion:

A number of factors which relate to the problem of obtaining optimum adhesion were not evaluated in this project.

One factor which is likely to affect the level of adhesion is the film of moisture adsorbed on the surface of the metal at priming. This variable is undoubtedly influenced by the temperature of the metal and by the relative humidity at the time the priming is performed. High relative humidity is also considered to be detrimental to the quality of bonds made with most adhesives, in that moisture is likely to condense in the wet prime coating after it has been chilled by the evaporation of solvent. Although actual determinations were not made in the course of this project, relative humidity was believed to be in the range from 40 to 60 percent in the priming area. Early in the project, it was found that facing primes of "FM-47" tended to "blush" unless the surfaces were warmed before and after the adhesive was applied.

Although the "water-break" test is often specified as a quality control test for adhesion, a formal evaluation of the correlation between water-break and adhesion was not performed in this project. The technicians who conducted the cleaning operations on the test facings reported that no "water-breaks" were observed on rinsed, acid-treated facings, even when very short acid-immersion times were used. Since the facings were usually rinsed as quickly as possible after being removed from the alkaline and acid treating tanks, it was not practical to determine if the solution films tended to break before the rinsing was performed. More advanced studies of the physical characteristics of surface films in relation to the preparation of metal surfaces for adhesion are currently being conducted by the Franklin Institute under Air Force Contract No. AF 33(616)-2347.

The effect of the temperature of the air during the force-drying operation was not directly evaluated, but this temperature should be kept below 140°F if the re-formation of oxides on the surfaces of the sheets is to be avoided.

According to published literature, most acid treatments used on aluminum surfaces do not etch the metal itself but merely remove the oxide. (Hydrochloric acid is a notable exception.) One accepted theory is that the oxide film is replaced by a more stable, compact, chemical film which resists the re-formation of oxides. Hexavalent chromium (as found in sodium dichromate and chromic acid) inhibits the attack of acids on aluminum and most other metals, and is believed to bring about the formation of a complex chromate compound which is particularly stable and resistant to corrosive attack.

It should be noted that, although the aluminum sheet stock used in this project was procured from more than one manufacturer, no distinction was made in the results of the evaluations of cleaning variables.

I - F, Continued

It is probable that the types of lubricating, cleaning, and heat-treating methods used in the manufacture of the aluminum may have some significance in the choice of the cleaning-process conditions used for developing maximum adhesion.

The only facing alloys on which cleaning studies were performed in this project were alclad 248-T3 and alclad 758-T6. The conclusions derived from these studies are applicable only to the clad versions of these alloys; the bare alloys are undoubtedly more reactive and may require shorter acid-immersion schedules. It is likely that the acid-treatment characteristics of very thin (0.008 and 0.012 inches) clad sheets approach the characteristics of the bare alloys because of the migration of reactive alloying constituents through the thin layer of cladding material. Although thin-gage sheets of the relatively pure aluminums such as 2S and 3S would require somewhat shorter acid-immersion times than would thicker sheets of the same alloy, because of their lower heat capacities and thinner oxide films, the lack of diffused alloy constituents in their surfaces would tend to make them less reactive than thin-gage clad materials.

The majority of research on the cleaning variables in adhesive bonding has heretofore been performed by the use of the "lap-shear" test. It should be observed that quantitative results from this type of test are often affected asymptotically by the yield strength of the metal, and do not necessarily reflect the strength of the bond in adhesion to the metal surfaces.

TABLE 18  
CLEANING CYCLES USED ON FACING MATERIALS BY NINE HONEYCOMB SANDWICH MANUFACTURERS

April, 1953

(Order of presentation bears no relation to that shown in other "Survey" tables)

PLANT	VAPOR DEGREASE	ALKALINE CLEANER	RINSE	ACID CLEANER	RINSE	DRY	PRECAUTIONS & MAX. STORAGE TIME BETWEEN CLEANING & PRIMING
A	None	"OAKITE 61"	Hot Water Jet, By hand	SD-SA 4:10:30 150° 1 min.dip	Hot Water Jet, By hand	Open Air Wooden Pallets	Stored in drying racks for as little time as possible
B	None	"SPREX A.C."	Hot Water Dip	SD-SA 4:10:30 Air Agitated 3 min.,	Hot Water Dip	Force Air Dry	Wrapped in paper
C	None	"TURCO 262"	200° Water	"DIVESTER 5Lk" Roof Temp.	Cold Water	Oven	4 hrs. Maximum
D	None	"TURCO 262"	Hot Water	Chromadize Chromic Acid 120°F	Hot Water	Oven 160° F	—
E	None	"KELITE II" 180° Air Agitated, 11 min.	Water 160°	"TURCO"	Hot Rinse and Spray	Oven	8 hrs. Maximum
F	None	"Any good alka- line soap"	Cold Water 2-5 min. Dip & 10 min.-180°F	Unheated 3 to 10 min. Cold Spray. 2 min.	Spray 2-5 min. Hot Water Dip, 2 min. 180-200°F	Oven 250°F 5 min.	8 hrs. usually, 48 max., if damp solvent wipe is used before baking.
G	Perchloro- ethylene	"TURCO AVIATION"	15 min. .	Cold, Denit- eralized rinse 5 min.	SD-SA 140°F 5 min.	Air Dry 15-30 min. 180°F	—
H	None	"SPREX A.C."	150°F	Cold Water Spray	Chromic-sulfuric on some panels.)	Cold Water Spray	Open Air 8 hrs. Maximum
I	Stabilized Trichloro- ethylene	"TURCO AVIATION"	180°F - 5 min.	Cold Water	5 pet. Chromic Acid - 130°F 2 min.	30 seconds-Cold 30 seconds-Hot	— 8 hrs. Maximum

ABBREVIATIONS: "SD-SA" - Sodium Dichromate-Sulfuric acid solution, recommended by Forest Products Lab.  
(4:10:30 - Indicates 4 parts dichromate, 10 parts sulfuric, 30 parts water.)

TABLE 19

Magnitudes of peel strengths obtained from consecutive panels made in adhesive-weight program, during two periods of possible cleaner solution deterioration.

## RELATIVE PEEL STRENGTH

Serial Number	Cell Size				Nominal Tape Wt. lbs./Sq.Ft.
	1/8	3/16	1/4	3/8	
C-117	---	---	Med.	---	0.086
C-118	Med.	---	---	---	0.098
C-119	---	---	Med.	---	"
C-120	Med.	---	---	---	"
C-121	Med.	---	---	---	"
C-122	---	---	High	---	0.086
C-123	Med.	---	---	---	0.079
C-125	Low*	---	---	---	"
C-126	Low *	---	---	---	"
C-127	Low *	---	---	---	"
C-128	Low *	---	---	---	"
C-129	---	---	High	---	"
C-130	---	---	Low*	---	"
C-131	---	---	Med.	---	"
C-134	---	---	Med.	---	"
C-135	---	---	---	Med.	"
C-136	---	---	Med.	---	"
C-137	---	---	Med.	---	"
C-138	---	---	Med.	---	"
C-139	---	---	Low.	---	"
C-140	---	---	---	Med.	"
C-141	---	---	---	Med.	"
C-142	---	---	---	Med.	"
C-143	---	---	Med.	---	"
C-147	High	---	---	---	"
C-148	Low	---	---	---	"
C-149	Low	---	---	---	"
C-153	---	Low*	---	---	"
C-154	---	Low*	---	---	"
(Cleaning solutions changed at this point.)					
C-155	Med.	---	---	---	"
C-156	---	Med.	---	---	"
C-157	Med.	---	---	---	0.086
C-167	---	Med.	---	---	0.079
C-168	---	---	Med.	---	"
C-169	---	---	---	Med.	"
C-170	---	---	---	Med.	"
C-171	Med.	---	---	---	"
C-172	---	---	Med.	---	"
C-173	---	---	Med.	---	"
C-174	Med.	---	---	---	"
C-177	Med.	---	---	---	"
C-179	---	Low	---	---	"
C-180	---	---	---	High	"
C-184	Med.	---	---	---	"
C-185	---	---	Med.	---	"
C-186	---	---	Med.	---	0.098
C-188	---	---	Med.	---	"
C-189	Med.	---	---	---	0.079
C-190	---	---	Med.	---	0.098
C-191	Low	---	---	---	"
C-192	Med.	---	---	---	0.079
C-193	Med.	---	---	---	"
C-194	Med.	---	---	---	"
C-195	Med.	---	---	---	"
C-196	Med.	---	---	---	0.086
C-199	Low	---	---	---	0.079
C-200	Low *	---	---	---	0.098
C-201	---	---	Low *	---	"
C-202	Low *	---	---	---	"
C-203	---	---	Med.	---	0.086
C-204	Med.	---	---	---	"
C-205	Low *	---	---	---	"

\* Displayed relatively high percentage of adhesion failure to facings, as well as showing relatively low peel strength.

TABLE 20

PEEL STRENGTHS OF PANELS MADE WITH TWO LAYERS OF "FH-47" TAPE,  
SHOWING EVIDENCE OF CLEANING PROCESS DETERIORATION

Facings: Alclad 24S-T3, 0.016" thick, cleaned in hot alkaline solution and immersed 5 minutes in 140°F solution of sulfuric acid and sodium dichromate, hot rinse. Age of acid solution variable.

Core: Al 1/8-.0015, 0.625" thick, primed in roller coater.

Tapes: One .05 lb./sq.ft. (nom.) tape at facing; one .07 lb./sq.ft. tape at core on each side tested.

Note:

Tensile specimens from these panels failed in core material.

Failure Coding:  
 A - Adhesion  
 AC - Adhesion and cohesion mixed  
 C - Cohesion

PANEL NUMBER	CELL SIZE	TOTAL TAPE WT. #/SQ. FT.	CORE-FRAME #/#/SQ.FT.	MACING-FRAME #/#/SQ.FT.	(SIDE TEST) ADHESIVE WEIGHTS	AVERAGE (2 TO 4 SPECIMENS)	LOW READING	THREE-INCH PEEL					CONDITIONS OF FACING PREPARATION
								PET. OF INCH-LBS.	AVERAGE	FACING	AC	C	
30	1/8	.131	.012	.002	277	85	5	95	--	--	--	--	Pacings cleaned with relatively old cleaner solutions shortly before being discarded.
151	1/8	.130	.009 approx	.0004	99	83	70	30	--	--	--	--	Pacings cleaned with relatively old cleaner solution (same lot as Panel C-154; other facing cleaned in relatively new solution).
187	1/8	.125	.009 approx	.001	.96 (old facing) 180	68	90	10	--	--	--	--	Pacing on one side cleaned in old cleaner solution (same lot as Panel C-154; other facing cleaned in relatively new solution).
					.001 (new facing)	85	--	100	--	--	--	--	

TABLE 21

RESULTS OF PERIODIC ANALYSES OF ACID CLEANER SOLUTION

(Performed by C. M. Ball, Assayer Chemist, Berkeley, California)

Panel cleaned at approx. time of analysis	Equivalent Sulfuric Acid Pct.	Chromium		Iron Pct.	Aluminum Pct.	Cl PPM	Si Pct.
		Hex Pct.	Tri Pct.				
C-1	22.05	0.84	0.006	0.005	0.015	Nil	---
C-30	20.45	0.68	0.08	0.011	0.020	10	---
C-58	18.10	0.51	0.31	0.22	0.06	10	.08
Note: At this point, hexavalent chromium was boosted by adding sodium dichromate.							
C-66	18.0	1.23	0.39	0.31	0.31	10	
C-149	14.8	0.37	0.55	0.30	0.28	40	.02
C-154	14.7	0.88	0.57	0.34	0.16	50	.01
Note: Acid and alka- line solutions changed here.							
C-155	21.6	0.84	Nil	Nil	0.005	Nil	Nil
C-200	18.35	0.54	0.21	0.10	0.08	10	0.01

TABLE 22

UNCLEANED FACINGS

Facings: Alcold 24S-T3, .016 thick, mill finish (not oiled) primed with dilute "FM-47" on unlettered side, without cleaning. Bonded (stencilled side out) to primed core with one "FM-47" tape, each side.

ADHESIVE WEIGHTS	THREE-INCH PEEL				FLATWISE TENSILE				REMARKS
	Average Actual	Average Specific	Low Rig.	Failure	Average Actual	Avg. Specifc	Pct. or Avg.	Failure (all tape-to-core)	
All failed in pure adhesion at peeling									
.072	.009 approx	.143	43	300	70	883	6180	90	Ad+Co Overcured 15 min.
.078	.009 approx	.145	52	360	76	944	6500	87	Ad+Co
.071	.009 approx	.136	52	382	80		616	4530	96 Ad+Co
.080	.009 approx	.149	53	360	88		653	4380	96 Co
133	.003	.1/8 - .0015	Core Metres/ft						-
132			Panel No.						-

TABLE 23

**EXPLORATORY INVESTIGATIONS OF VARIOUS ADHESIVE  
PARAMETERS OF AUTOMOTIVE PAINTS FOR ADHESION**

**Materials:**

Paints: Alcold 245-73, .016 inches thick, (2 to 4,  $10^6 \times 10^6$  per sec.), degassed in air-activated acid solution for 5 minutes at  $104^\circ\text{F}$ . Time and temperature variable in some instances; later found to be critical with respect to each other), hot spray rinsed, dried in hot air, and primed with  $\text{TiO}_2$  to 0.002 lbs./sq.ft., approx.

Tapes:

Carb: Al 1/8-.002-.662, thick, unprimed. (Panel:  $5'' \times 9''$ )

Acid:

Initial constituents: 1 part sodium dichromate, 10 parts concentrated sulfuric acid, 30 parts water. (22.4 per. equiv.  $\text{H}_2\text{SO}_4$ , .56 per.  $\text{Cr}^{6+}$ ) Acid of solution and contaminants (naturally and artificially introduced) were variables. Concentrations determined by C.M.Ball Analytical Chemist. (Values in parentheses are estimated only. Vertical arrows indicate no analysis, but probable confirmation of trend.)

Notes: 1: The purpose of these investigations was to seek critical variables, warranting more comprehensive studies. The control conditions were found to be too critical to allow firm conclusions to be drawn from the majority of the experiments.

2: Panel specimens which did not fail in adhesion or local cohesion at peeling were rejected.

TEST NUMBER	DESCRIPTION of CLEANING VARIABLE ADJUSTMENT	ACID ANALYSIS (Per. of total solution)					ALKALINE Titration ("Congo Red" End Point) ml./ml.			TIME-TEEN PEEL			COMMENTS & CONCLUSIONS
		equiv. Sulfuric Acid	equiv. $\text{Cr}^{6+}$	% $\text{Cr}^{3+}$	% Al	% Cl	% Si	Panel Average	Group Average	Inch-lb.	Inch-lb.	Inch-lb.	
216	Control	16.9	.41	.89	.18	.11	.12	.005	3.7	166	161	161	55
217										157	172	172	55
218										203	203	203	50
279	Hot cold alkaline cleaner	↑	↑	↑	↑	↑	↑	↑	3.6	150	177	177	52
224										201	201	201	30
260	Fresh alkaline solu- tion mixed ("TAKTES 61")	↑	↑	↑	↑	↑	↑	↑	8.2	142	139	132	60
225	2 parts sodium dichromate added to acid	15.6	2.7%	.30	↑	↑	↑	↑	8.7	116	116	112	50
261										125	125	125	60
229										104	119	119	60
230										129	129	129	60
232										135	132	132	60
266	Sulfuric acid added	19.6	2.53	.29	(.2)	↑	↑	↑	↑	172	162	162	70
297										170	170	170	50
233	Perrie sulfate added to acid	20.7	2.46	.31	.86	.12	.10	.012	↑	138	152	151	60
234										152	152	151	55
267										162	162	162	50
235	Chromium sulfate added to acid	↑	↑	(.9)	↑	↑	↑	↑	↑	133	163	163	60
236										175	175	175	55
269										182	182	182	70
237	Table salt added to acid	21.0	2.36	.93	.96	.12	.06	.011	↑	151	154	154	55
238										168	168	168	60
290													

(continued next page)

No.	Variable	ACID ANNEALING TEST.						SINTERED IRON						PEEL STRENGTH, at 100°F.						COMMENTS & CONCLUSIONS							
		Reflux Cr <sup>3+</sup>	Chromite Cr <sup>3+</sup> Acid	Al <sub>2</sub> O <sub>3</sub>																							
361	New acid solution acid added	21.6	.01	.006	cr	W11	9.2	110	130	180	120	130	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
362	New type of alumina solution	21.6	.02	.015	cr	W11	6.4	120	120	130	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
363	Alumina solution ("WATER 61-4")	21.6	.05	.04	cr	W11	.005	6.0	120	120	130	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
364	Effect of use after 30' 30° x 10° package	21.4	.75	.05	cr	W11																					
365	Water cleaned																										
366	After annealing over- heating to 150°F new thermocat & virtue installed	20.2	.65	.17	.03	cr	W11	.005	6.1	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
367	New control smoother facing prior to un- lettered side only	18.9	.55	.21	.03	cr	W11	.008	↓	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
368	Smooth	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
369	Reflux prior to un- lettered side only																										
370	Reflux up to 300°F before sintering																										
371	Chromite is same rock but not right																										
372	1 part sodium dichro- mate added to acid	19.1	1.32	.22	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
373	1/2 part sodium dichro- mate added to acid	2.63	.19	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
374	Sulfuric acid added	23.9	2.50	.19	.03	cr	W11	.006	↓	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
375	New acid solution 1/2 part dichromate Add one part dichro- mate to acid	4.0	(0)	(0)	(0)	(0)	(0)	↓	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
376	Add 2 parts dichro- mate to acid	1.82	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
377	1/2 part dichromate Add 1/2 part dichro- mate to acid	21.2	2.76	.09	.007	cr	W11	.004	5.9	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
378	1/2 part dichromate Add 1/2 part dichro- mate to acid	19.5	2.65	.50	.022	cr	W11	.005	↓	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
379	10 minutes in acid 10 minutes in acid	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑	↑
380	10 minutes in acid																										
381	Acid temperature																										
382	5 minutes in acid (control)																										
383	10 minutes in acid																										
384	Acid temperature down (110°F)																										
385	Acid temperature up (160°F)																										
386	Acid salt & Ferric sulfate added to acid	20.2	2.68	.45	.02	cr	W11	.006	5.9	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	
387	Acid salt & Ferric sulfate added to acid	20.5	2.30	.34	.02	cr	W11	.01	5.1	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	120	

TABLE 2b

EVALUATIONS OF PROCESS VARIABLES  
IN THE CHEMICAL PREPARATION OF ALUMINUM  
SANDWICH PACINGS FOR ADHESION

**Conditions:** One 10" x 10" alclad sheet (variable alloy and thickness) in 28 aluminum rack cleaned in 170°F solution of "OMAITE 6L-A" at 7 oz/gal for 10 minutes; hot spray rinsed 1 minute (approx.); dipped in hot, air-agitated solution of (minimally) one part sodium dichromate, ten parts sulfuric acid, 30 parts water (22.4% equiv. sulfuric acid, 0.84% Cr<sub>2</sub>O<sub>3</sub>). Temperature: 140° or 160° ± 4°F. Acid/immersion times varied during run at each controlled condition. Removed from acid solution and immediately cold spray rinsed for 30 sec., approx. (pH of rinse water: 8.3 to 9.3). Force dried in warm air for 15 to 20 min. Warmed sheet brush-primed within one hour after cleaning with dilute, dyed "PM-47" and force-dried with hot air gun within one hour of cleaning. Sheared into two 5" x 10" pieces; one piece bonded to unprimed al 1/8-.002 with three layers of heavy "PM-47" tape. Cure: five minutes contact pressure preheat; 55 minutes at 345°F, 35 psi. Two peel specimens run from each panel.

Run No.	Panel No.	Parameter	Pacings	ACID BATH SOLUTION CONDITIONS								THREE-INCH PEEL	Tensile Surface Strength, lb/inch²	Remarks on Surface	Avg. P.I.				
				Composition Pct. by Weight *							Temp.	Time	Average	Percent Failure (all tape to face)					
				H <sub>2</sub> SO <sub>4</sub>	Cr <sub>2</sub> O <sub>3</sub>	Cr <sup>3+</sup>	Fe	Al	Cl	Si	Deg.	Min.	Inch-lbs.	Ad					
A	416 417 418 419 420 421	(Groups C, F, G, T were used to augment the plotted control curves)	.016 Alclad 248-T3	22.8	.60	.15	.082	.02	0	.008	140°F	1/2 1 2 3 10 20	50 76 111 106 202 190	75 60 65 51 50 50	770 470 450 360 465 462	---	---	35	
	422 423 424 425 426 427 428			21.6	.53	.80	.033	.06	0	.008	160°F	1/4 1/2 1 2 3 10 20	79 68 108 136 160 185 180	88 80 65 60 55 50 50	680 580 485 370 365 705 185	---	---	35	
	429 430 431 432			Inadequate Alkaline Cleaning + (5 min at 160°F, 5 oz/gal)	.016 (22.8)	(.60)	(.15)	(.082)	(.02)	(0)	(.008)	140°F	1/2 1 2 3	86 38 104 189	98 95 70 55	1290 450 1010 1160	Stains and streaks showing pattern of lettering	---	36
	696 697 698 699 700			20.4	.54	.80	---	---	---	---	140°F	1 2 3 4 5	13.0 191 206 208 179	85 55 15 15 55	---	---	---	36	
	472 473 474 475			(21.0)	(.45)	(.30)	(.3)	(.08)	(0)	(.008)	140°F	3/4 1 2 3 4	163 161 156 171	60 60 50 40	138 253 665 900	Glossy bright surface	---	36	
	691 692 693 694 695			20.4	.54	.80	---	---	---	---	160°F	1/4 1/2 3/4 1-1/4 6	94 106 171 173 210	95 85 55 55 25	---	---	---	36	
	494 495 491 497 498			(21.0)	(.40)	(.35)	(.035)	(.12)	(0)	(.008)	140°F	3 5 7 10 20	158 211 281 266 293	60 60 40 20 30	123 68 42 42 73	---	---	37	
B	640 641 642 643 644 645	Effect of Temperature on Peel Strength	.032 Alclad 248-T3	(21.0)	(.68)	(.10)	---	---	---	---	140°F	2 4 6 8 10 20	163 300 271 277 292 316	65 40 25 25 20 25	---	---	---	37	
	661 660 660 661 662 663			(21.0)	(.60)	(.15)	---	---	---	---	140°F	1 2 3 4 5 7	66 167 164 233 266 309	85 60 55 55 30 30	543 123 65 61	---	---	37	
	680 681 682 683			(21.0)	(.40)	(.35)	(.035)	(.12)	(0)	(.008)	160°F	1 2 3 5 10	148 867 899 836	60 45 40 40	543 123 65 61	Grey, mottled	---	37	

(continued to next page)

TABLE 8<sup>a</sup>, continued

Group	Panel Number	Parameter	Facing	ACID SOLUTION CONDITIONS							TENGE-INCH PEEL				Remarks <sup>b</sup>	Ref.		
				Composition Pct. by Weight <sup>c</sup>							Temp.	Time	Average	Percent failure (all tape to face)	Electric current mA			
				HgSO <sub>4</sub>	Cr <sub>2</sub> O <sub>3</sub>	Cr <sub>3</sub> O <sub>4</sub>	Fe	Al	Cl	Ni								
K	469			.016	(21.0)	(.45)	(.30)	(.3)	(.08)	(0)	(.008)	160F	1 2 5 10	79 180 193 104	85 50 50 50	203 95 70 55	— (No zinc found in solution afterward.)	39
K	469	Alloy	.016 Alcohol 750-75		(21.0)	(.45)	(.30)	(.3)	(.08)	(0)	(.008)		1 1-1/2 2 4	180 110 215 216	65 75 50 50	275 250 160 395	—	39
L	464				(21.0)	(.45)	(.30)	(.3)	(.08)	(0)	(.008)							
L	465																	
L	466																	
L	467																	
M	476																	
M	477	No Agitation	.016 Alcohol 750-75		(21.0)	(.45)	(.30)	(.3)	(.08)	(0)	(.008)	160F	1/2 1 1-1/2 1-3/4	56 119 193 193	55 72 55 55	122 115 115 120	—	46
M	478																	
M	479																	
N	615																	
N	616																	
N	617																	
N	618																	
N	619																	
O	558																	
O	556																	
O	557																	
O	558																	
O	563																	
P	609	Effect of Alcohol by dilution ratio	.016 Alcohol 750-75															
P	555																	
P	559																	
P	560																	
P	561																	
P	562																	
P	610																	
P	613																	
P	618																	
Q	588																	
Q	589																	
Q	590	Over-age Acid solution																
R	500																	
R	501																	
R	502																	
R	503																	
R	504																	
R	505																	
S	646																	
S	648																	
S	649																	
S	650																	
S	651																	
T	566																	
T	563																	
T	568																	
T	564																	
T	567																	
U	575																	
U	573																	
U	573	1:10:30																
U	569																	
V	590																	
V	579																	
V	580																	
V	581																	
V	591																	
V	592																	
V	593																	
V	600																	
V	602																	
V	606																	
V	607																	
V	608	Effect of Dilute Concentration	4:10:30															

(continued to next page)

TABLE 24, continued

Group	Specimen No.	Parameter	Facing	ACID SOLUTION CONDITIONS								THREE-INCH PEL		Remarks on Facing	No. of Specimens	
				Composition Pet. by Weight *								Temp.	Time	Average	Percent Failure (all tape to face) M	
				H <sub>2</sub> SO <sub>4</sub>	Cr <sup>6+</sup>	Cr <sup>3+</sup>	Po	Al	Cl	Si	Deg.	Min.	Inch-lbs.	M		
Z	667	Low Acid	.016 Alkaline SHS-T3	16.0	1.08	(0)	(0)	(0)	(0)	(0)	140F	1-1/2	49	72	---	---
	668											3-1/2	108	55	---	---
	669											2	143	50	---	---
	670											8	201	30	---	---
Y	671										160F	3/A	96	72	---	---
	672											1-1/2	122	65	---	---
	673											2	190	55	---	---
	674											3-1/2	160	65	---	---
Z	721	High Acid	.016 Alkaline SHS-T3	(33.5)	(.97)	---	---	---	---	140F	1	51	95	---	Stains & streaks showing pattern of lettering #3	63
	722										2	95	90	---	---	63
	723										3-1/2	196	50	---	---	63
	724										2	280	55	---	---	63
AA	675	High Acid	.016 Alkaline SHS-T3	(33.5)	(.97)	---	---	---	---	160F	8	825	50	---	---	63
	676										1	68	95	---	---	63
	676										1	69	90	---	---	63
	677										1-3/4	155	50	---	---	63
AB	701	High Acid (not plotted)	.016 Alkaline SHS-T3	33.5	.97	---	---	---	---	140F	1	142	65	---	---	63
	702										2	157	55	---	---	63
	703										3	200	55	---	---	63
	704										2	172	65	---	---	63

\* Determinations made by C. N. Bell, Assayer-Chemist, Berkeley, Calif. (Values in parenthesis are estimated or interpolated only.)

\*\* Many of the facings which were given acid immersions of the order of 1 minute showed red-brown iridescent stains, not noted in remarks.

\*\*\* Facings 0.016" thick showed brighter, shinier surfaces after acid treatment than did heavier gauges.

† First group run; originally intended as control. Evidence of lettering remaining after alkaline cleaning indicated ineffectiveness as a result of over-use in previous evaluations. Concentration, immersion time, and temperature were raised before running other groups.

‡ Last group run in the series. Appearance of facings indicated that alkaline degrease was becoming ineffective from excessive use. Shape of curve was similar to that of Group "C".

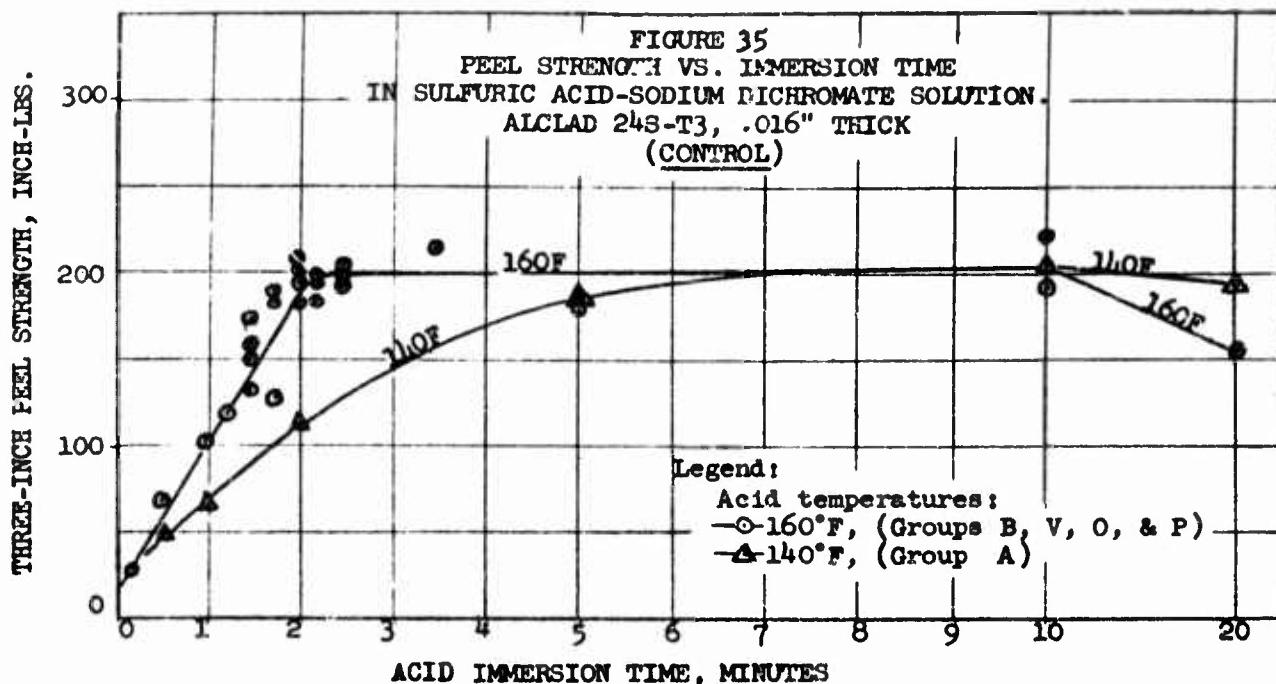


Figure 35: Control curves, Alclad 24S-T3 facings, .016 inches thick in air agitated solution containing (nominally) 1 part sodium dichromate, 10 parts concentrated sulfuric acid, 30 parts water. Alkaline cleaning with hot rinse precedes treatment; cold rinse and force-dry follow. Facings primed with "FM-47", bonded with 3 layers "FM-47" tape to al 1/8-.002 core. (From Table 24). Note: some groups plotted here are also plotted in evaluations of other parameters in succeeding graphs.

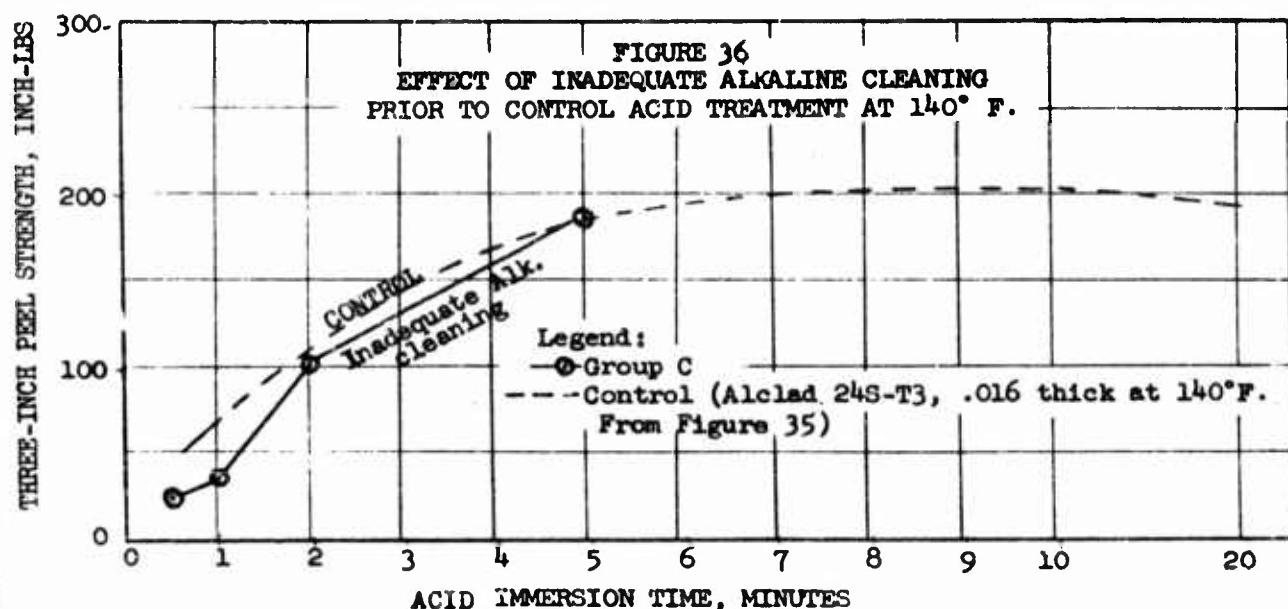
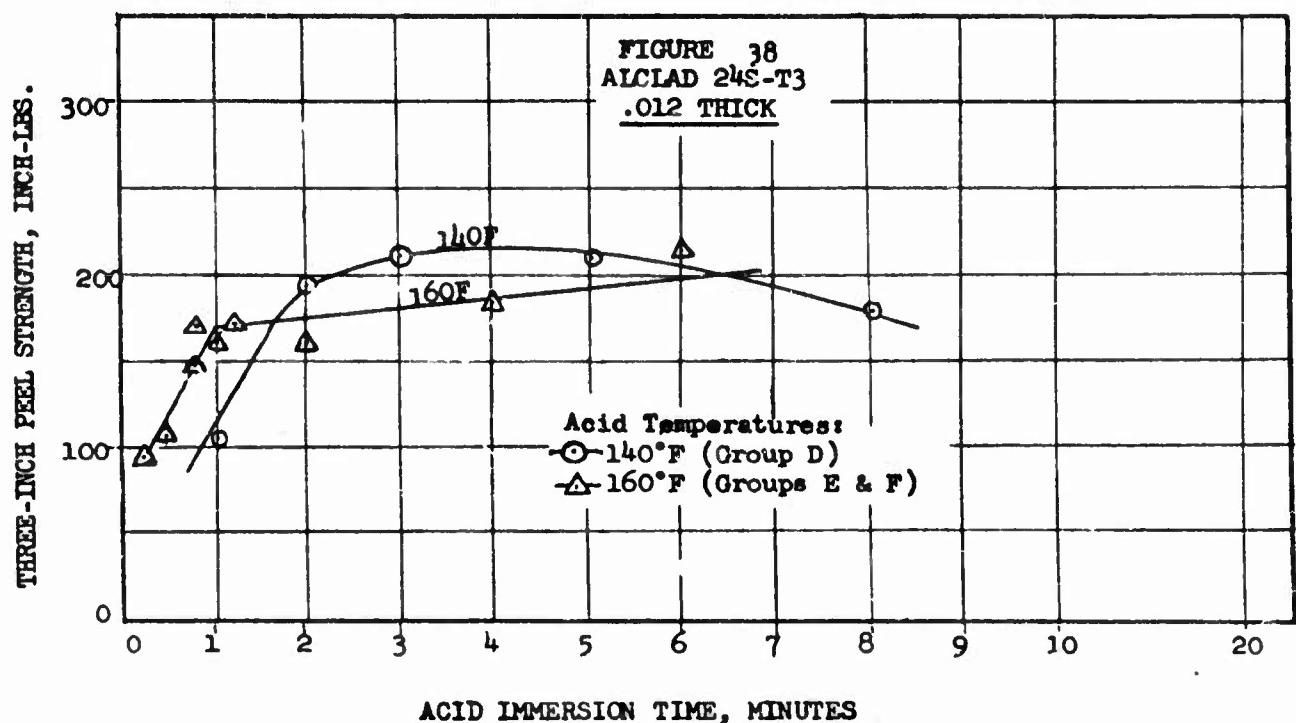
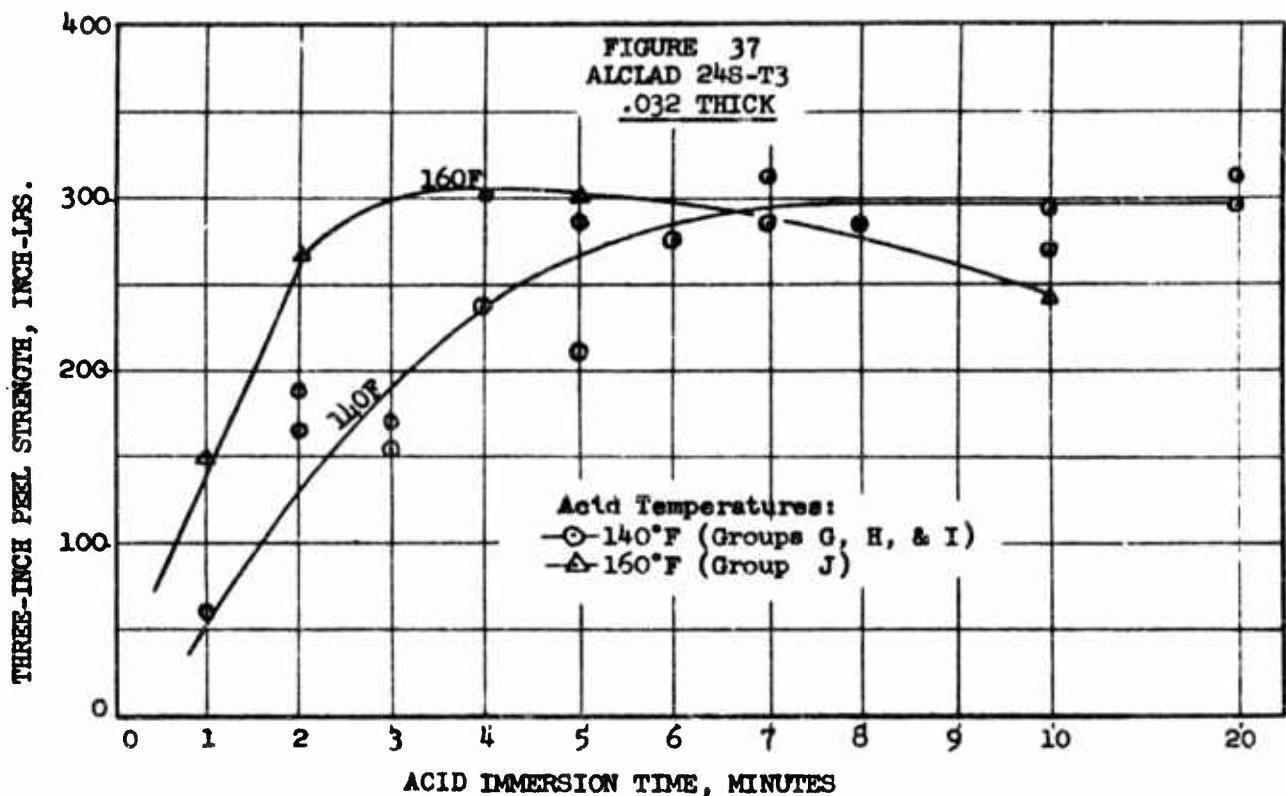


Figure 36: Effect of inadequate alkaline cleaning cycle on first group run in series. Facings showed residual deposit, with pattern of lettering in evidence, after alkaline treatment, eliminated after concentration, temperature, and immersion time in alkaline cleaner were increased. Similar appearance and curve shape was in evidence on 160F "High Acid" group, Figure 34. (From Table 24)



Figures 37 & 38: Effect of facing thickness (0.032 and 0.012 inches) on relationship between peel-strength and acid-immersion time at two acid temperatures. (From Table 24)

THREE-INCH PEEL STRENGTH, INCH-LBS.

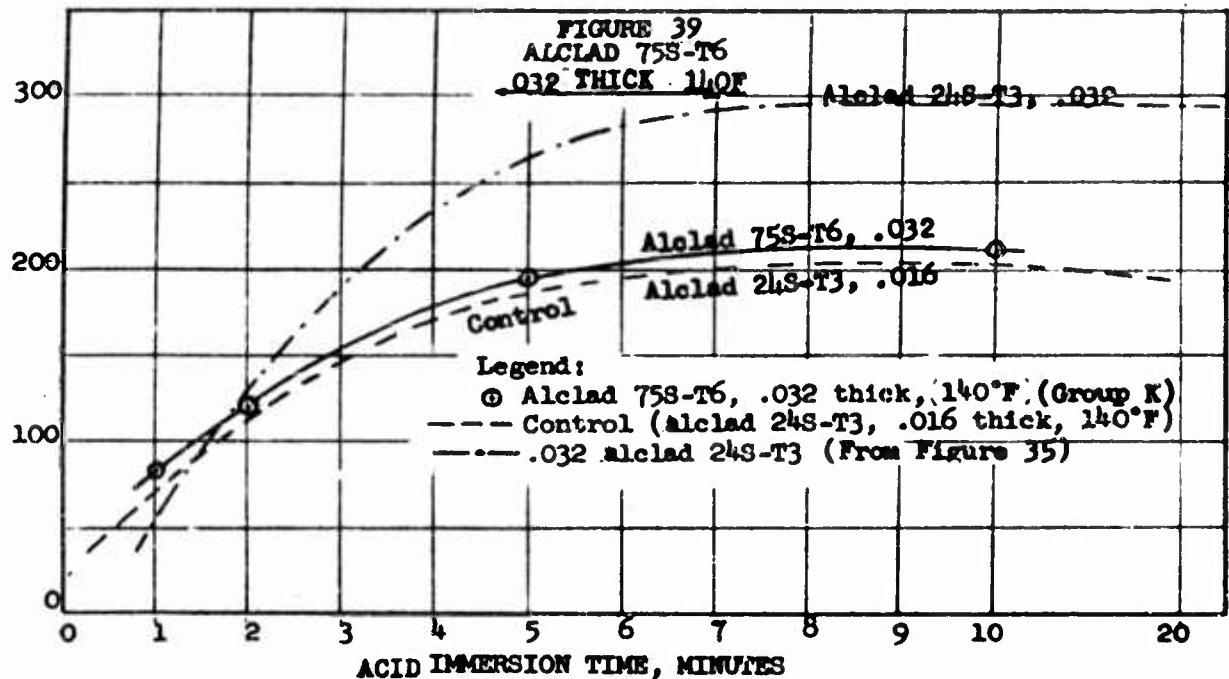


Figure 39: Peel vs. acid-immersion time at 140°F of alclad 75S-T6, .032 thick showing similarity with control (alclad 24S-T3, .016 thick) and lower values than alclad 24S-T3 in same thickness. (From Table 24)

THREE-INCH PEEL STRENGTH, INCH-LBS.

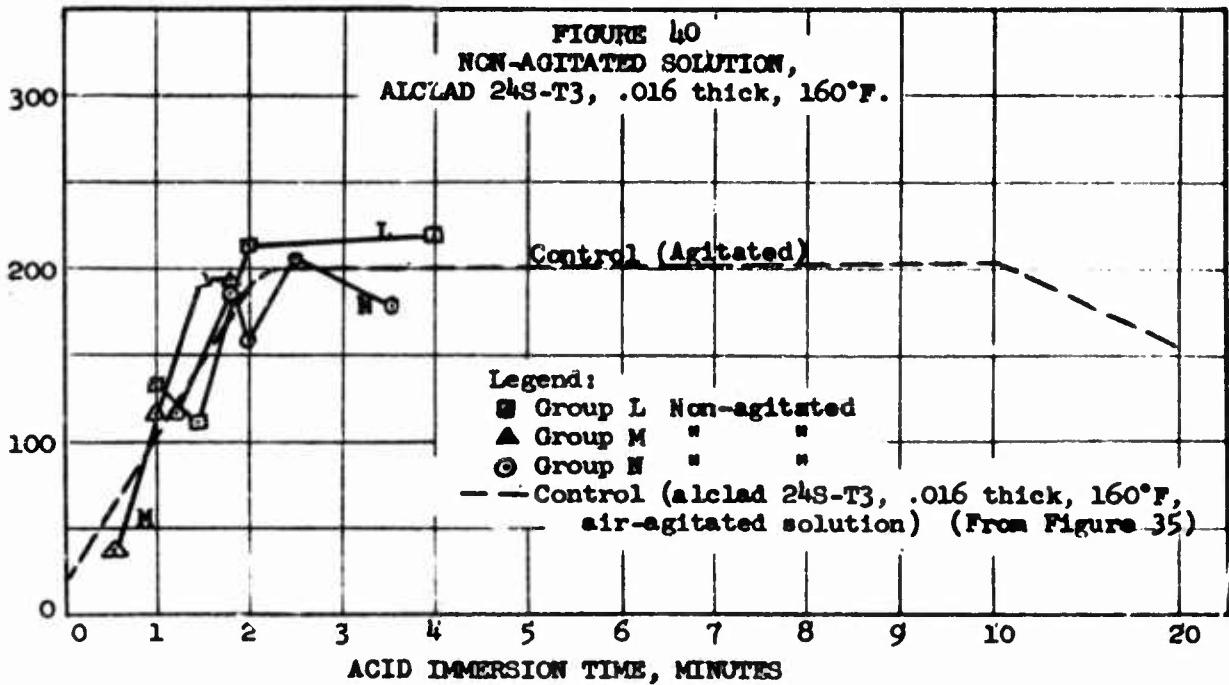


Figure 40: Effect of lack of air agitation of acid solution, showing wide degree of dispersion about control. (From Table 24)

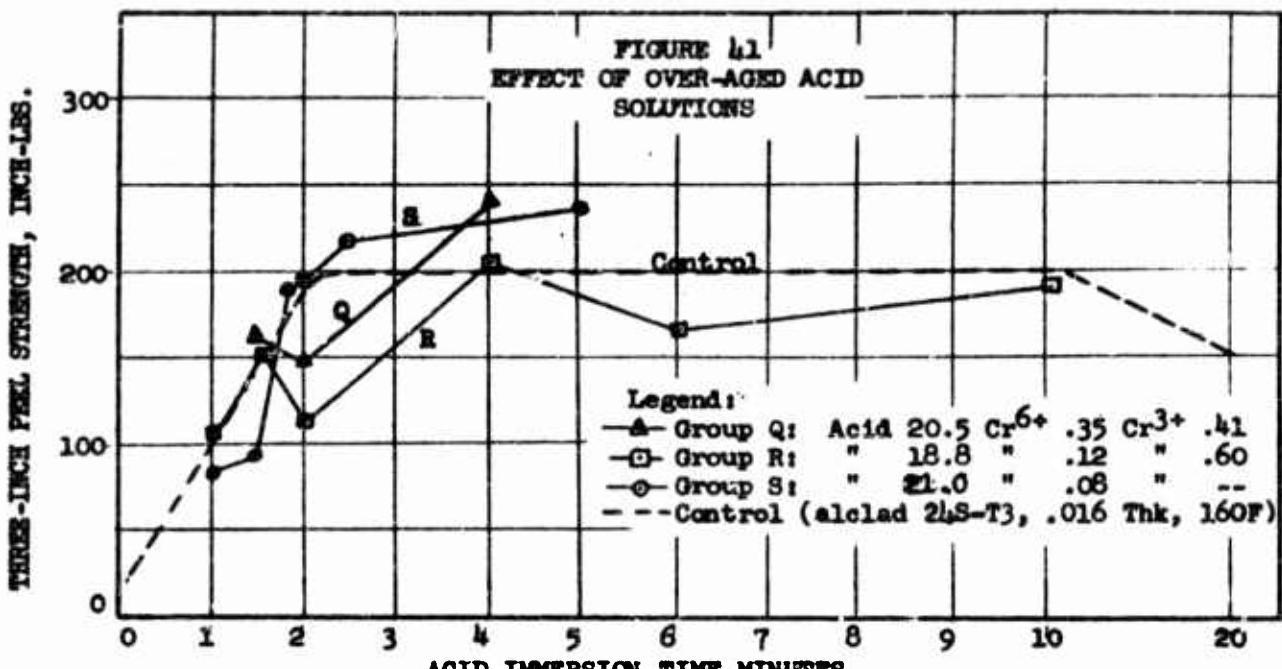


Figure 41: Peel strength vs. acid-immersion time, of alclad 24S-T3 facings .016 thick in over aged solutions at 160°F, showing high degree of dispersion about control. (From Table 24) Facings cleaned at longer times showed porous gray-white scale.

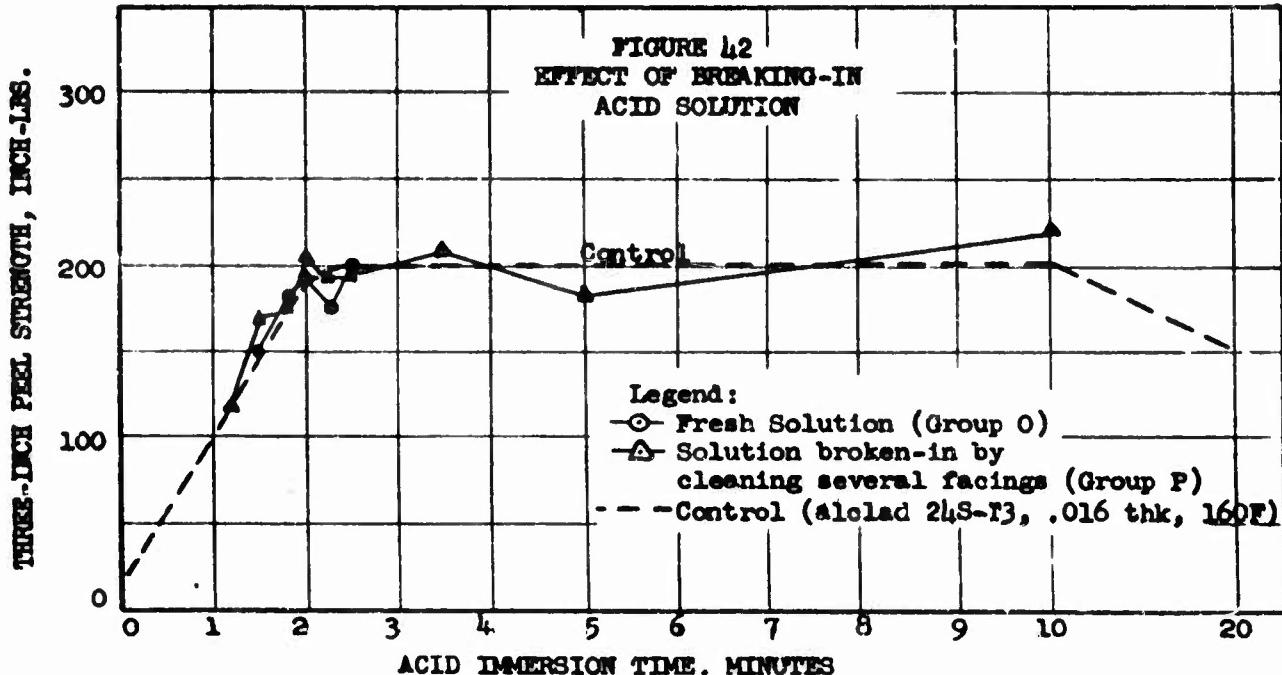
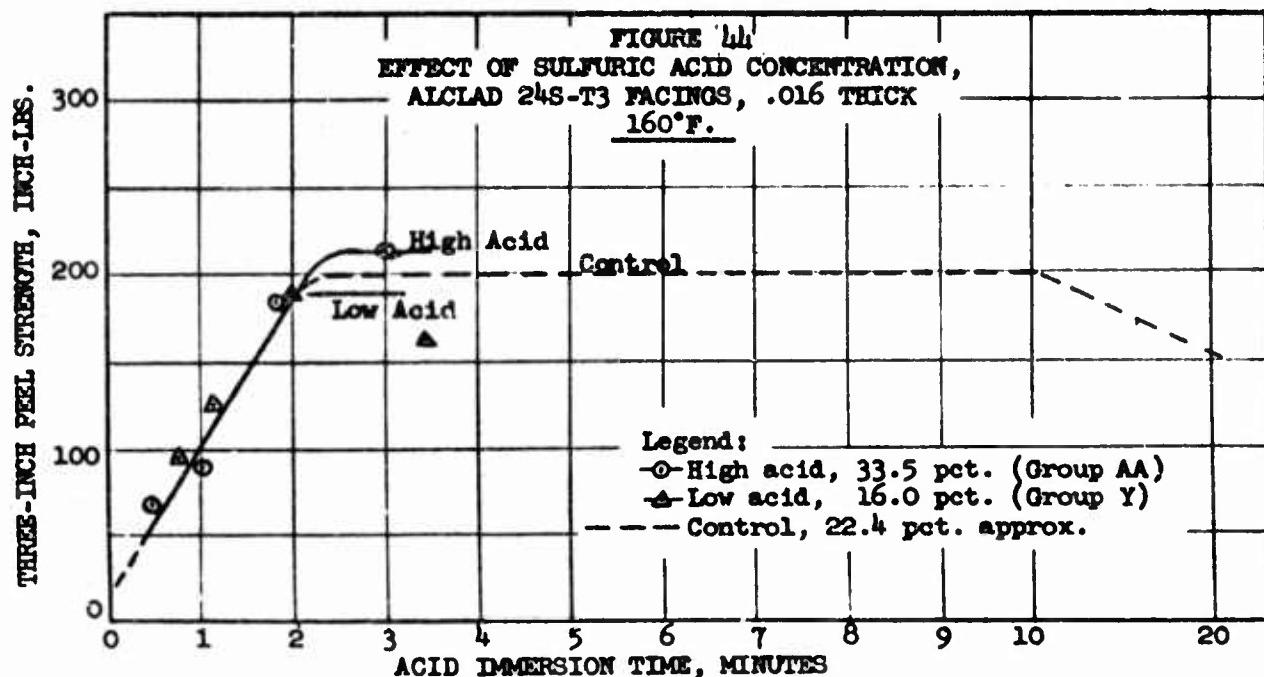
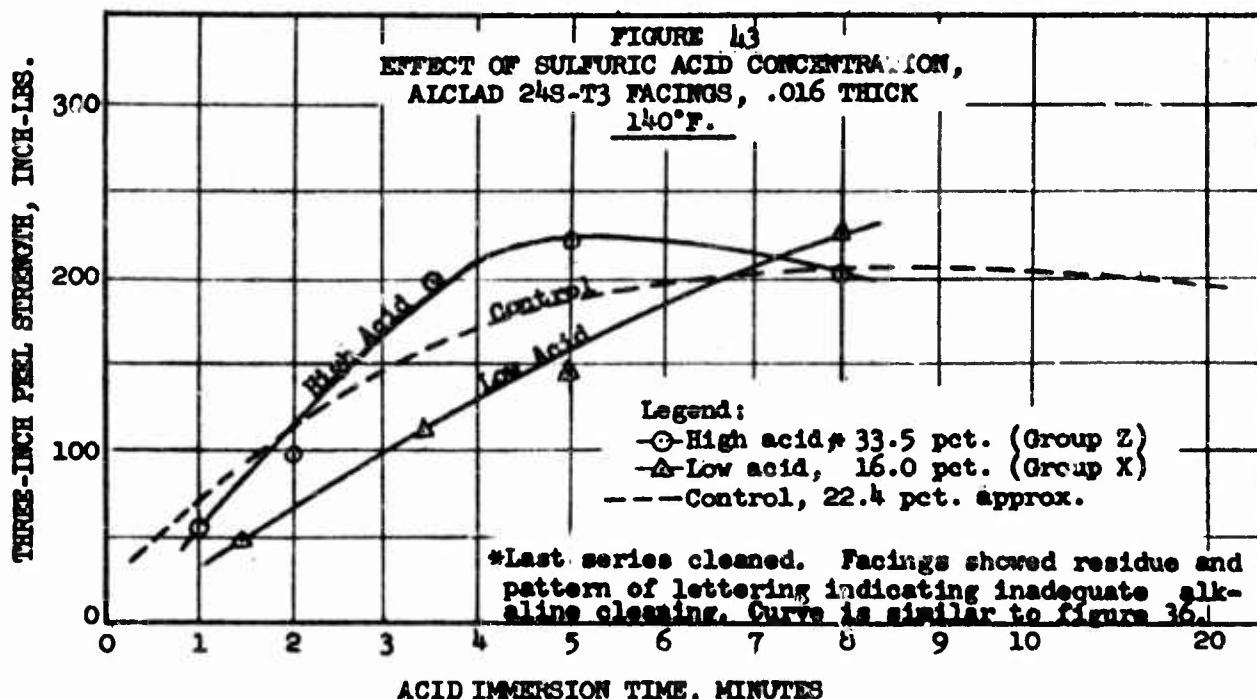
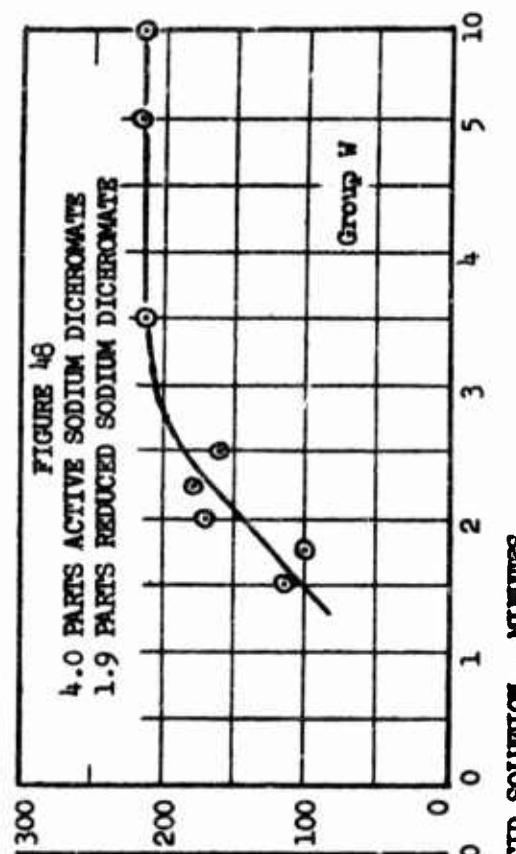
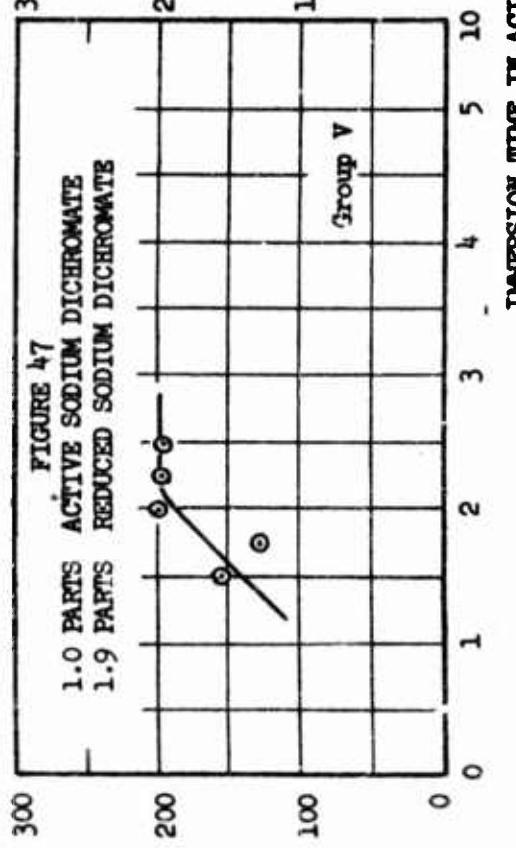
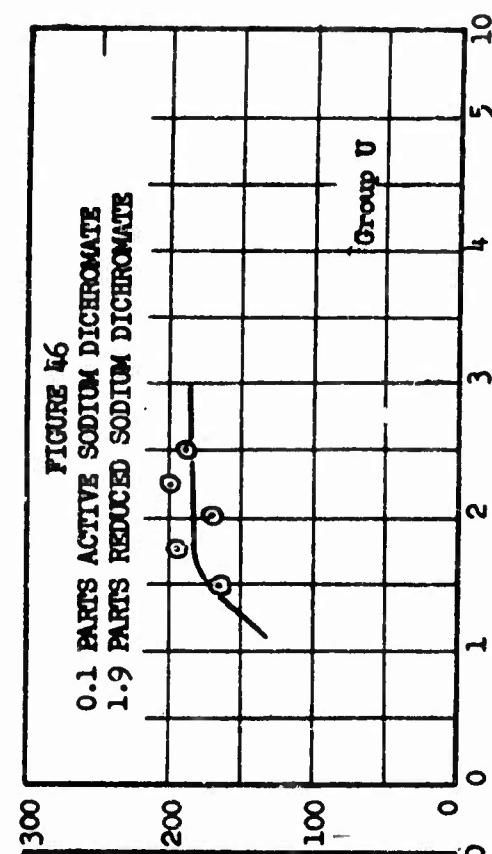
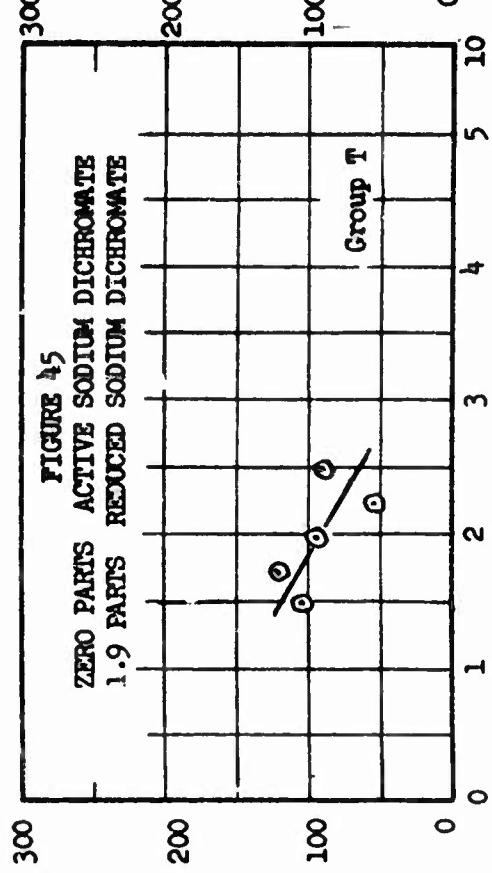


Figure 42: "Fresh" and "broken-in" acid solutions at 160°F used to clean alclad 24S-T3 facings, .016 thick, showing no change in immersion time characteristics and low degree of dispersion about control. (From Table 24)



Figures 43 & 44: Effects of high and low equivalent sulfuric acid content on peel strength vs. immersion time, Alclad 24S-T3, 0.016 thick, showing significant effect at 140°F and none at 160°F. (From Table 24)



FIGURES 45, 46, 47, & 48: Peel strength vs. immersion time in 160°F agitated acid solution, at various concentrations of sodium dichromate. (alclad 24S-T3 skins, 0.016" thk.). Chromium sulfate added to simulate typical depletion of hexavalent chromium. No other contaminants in excess. Primed test skin bonded with three FM-47 tapes to al 1/8-.002 core. One panel, two peel specimens per point. Adhesive & cohesive failures at skin only. (A "part" is that quantity dissolved in 10 parts conc. sulfuric acid, 30 parts water. "Active parts" are those in which the hexavalent chromium ( $\text{Cr}^{6+}$ ) in  $\text{Na}_2\text{Cr}_2\text{O}_7 \cdot 2\text{H}_2\text{O}$  has not been reduced to trivalent ( $\text{Cr}^{3+}$ )).

TABLE 25

PEEL VS. HOLDING TIME, HOT AND COLD RINSE

**Surface Preparation:** Thorough alkaline cleaning followed by 5 min. in agitated sulfuric acid - sodium dichromate solution at 140°F. Three minute variable temperature spray rinse.

**Priming:** One brush coat, "FM-47" adhesive in equal part of "FM-47" thinner, on warmed facing, dried with warm air.

**Materials:**  
 Facings = Alclad 248-T3, .016 in. thick  
 Adhesive = Three layers heavy "FM-47" tape  
 Core = Al-1/8-.002 cut .625 in. thick

Panel Number	Interval between drying & priming *	FACING PREPARATION		THREE INCH PEEL DATA				Remarks
		Prime Weight (one side) lb./sq. ft.	Post-acid rinse temperature °F.	Average In.-#	Low Reading Pct. of Average	Percent Failures		
						Adhesion at skin	Cohesion at skin	
282	20 days	.002	150(approx)	221	89	15	85	Exploratory Evaluation of Holding Time
283	"	.002	"	198	93	25	75	
284	"	.002	"	129	87	45	55	
255	100 days	.002	"	111	80	65	35	
256	"	.002	"	76	50	65	35	
257	"	.002	"	54	81	85	15	
258	"	.002	"	80	64	65	35	
446	5 min.	.002	"	189	96	50	50	Average of peels = 192 inch-lbs.
447	1 hour	.003	"	197	94	50	50	
448	1 day	.003	"	194	92	35	65	
449	1 week	.002	"	189	94	50	50	
450	5 min.	.002	65(approx)	203	89	50	50	Average of peels = 202 inch-lbs.
451	1 hour	.002	"	196	92	45	55	
454	1 day	.002	"	211	86	45	55	
453	1 week	.002	"	200	91	50	50	

\* - Storage: "Exploratory" series was suspended uncovered in shop area of honeycomb manufacturing plant. "Rinse temperature" series was suspended covered in room with cleaning tanks.

TABLE 26

## EXPLORATORY EVALUATIONS OF VARIOUS SURFACE PREPARATION METHODS

SPECIMENS: Alclad 24S-T3 facings, 0.016 inches thick, cleaned by various methods, primed with "TM-47" to 0.002 lbs/sq.ft.; bonded with three layers "TM-47" tape to Al 1/8-.002 core.

Panel Number	SURFACE PREPARATION				Electrical Surface Resistance <sup>a</sup> Micro-ohms	THREE INCH PEEL STRENGTH			
	DEGREASE	FINAL TREATMENT				Average (2 speci- mens)	Percent Failures at Facing		
		Solution	Temp.	Time Min., Sec.					
458	10 min. in alkaline solution* at 165°F	"DIVERSEY 514" in Pyrex Vessel (see Fig. 49)	70°F approx	1 2 4 10 20	295 54 6 53 93	98 156 204 135 63	90 75 60 60 90	10 25 40 40 10	
459	"								
460	"								
461	"								
412	5 min. same								
511	10 min. in alkaline solution* at 165°F	"DIVERSEY 514" in Stainless Steel Tank (see Fig. 49)	70°F approx	30 sec 90 sec 3 4 5 6 10 20	233 110 33 18 12 18 63 107	71 86 133 148 150 128 146 73	97 98 90 55 70 85 80 95	3 2 10 45 30 15 20 5	
512									
513									
514									
515									
516									
517									
518									
519	110°F			15 sec 45 sec 50 sec 1 75 sec	80 20 21 19 46 54 5 24	184 114 139 145 189 131 84 60	55 75 80 60 60 75 80 90	45 25 20 40 40 25 20 10	
520									
521									
522									
523									
524									
525									
526									
362	5 min. in alkaline solution* at 165°F	25% H <sub>2</sub> SO <sub>4</sub>	140°F	5	---	66	85	15	
363			140°F	5	---	69	85	15	
433	10 min. in alkaline solution* at 165°F	5% Chromic Acid	165°F	5	170	55	99	1	
414	Acetone wipe	(none)	---	--	1120	34	99	1	
415	CCL <sub>4</sub> wipe	(none)	---	--	240	30	99	1	
300	15 min. in alkaline solution* at 165°F	(none)	---	---	---	58	98	2	
301				---	---	57	98	2	
302				---	---	54	98	2	
413				---	---	53	99	1	

\* "OAKITE "61-A"

\*\* Average of 8 readings in "PALCO" (Model VT-II) Surface Resistance Analyzer

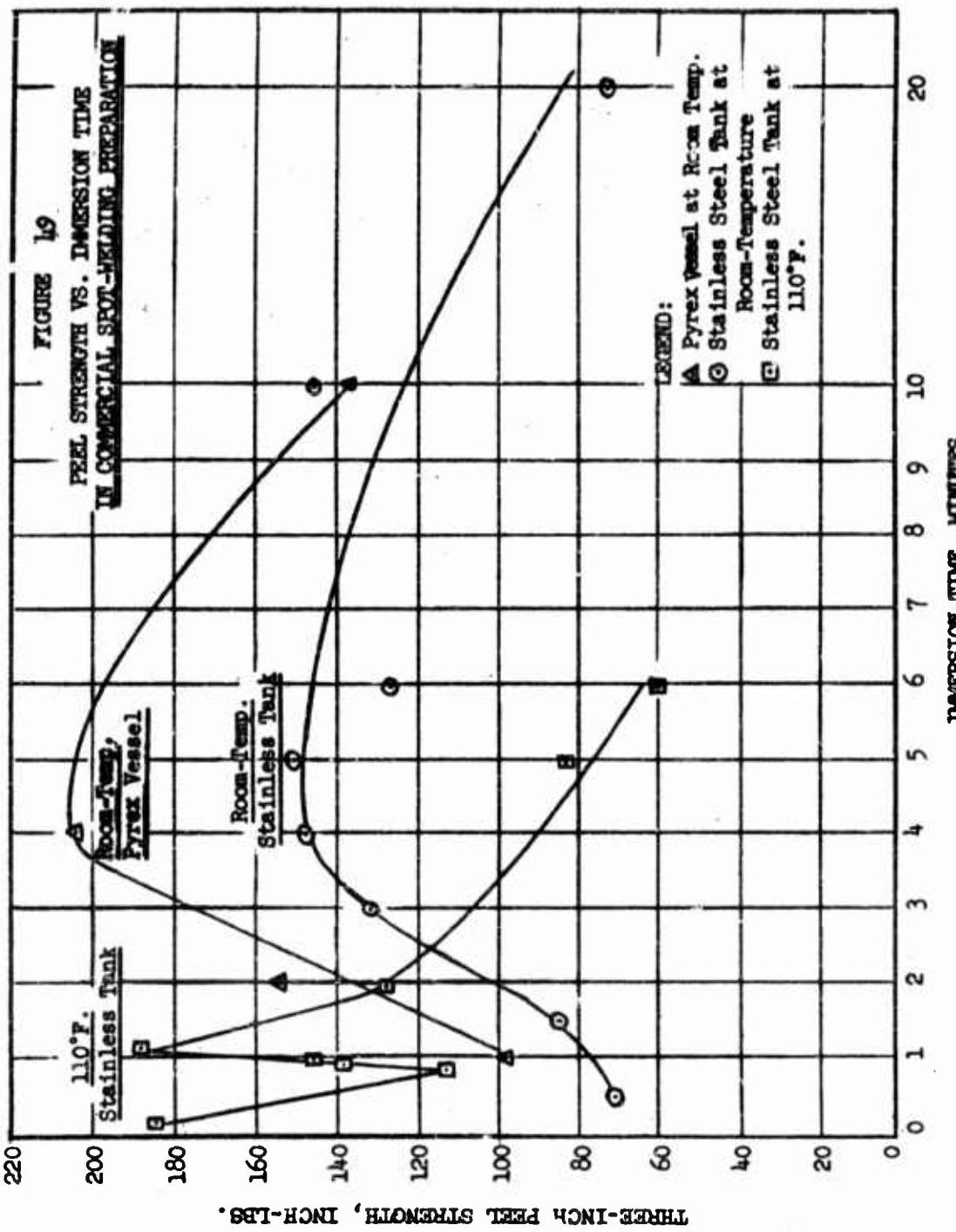


FIGURE 49: Evaluation of the effectiveness of "DIVERSEY 514" (a commercial spot-welding solution for aluminum) in preparing aluminum surfaces for bonding. (From Table 26). Curves represent two solution temperatures and two types of vessels. Facings of a leaded 24S-T3, 0.016" thick, degreased in alkaline cleaner, immersed in "DIVERSEY 514", cold rinsed, dried, primed with "FM-47", and bonded with 3 "FM-47" tapes to Al 1/8-.002 core.

SECTION II  
PROCESS AND EQUIPMENT DEVELOPMENT

Concurrent with the experimental studies of variables that affect bond strength, covered in Section I, evaluations of process and equipment variables were being performed by means of experimental and survey work. The scope of these developments included core-priming methods, the coating of facings in the sheet and coil forms, methods of processing coiled aluminum, control of flatness in curing fixtures, and evaluations of corrosion-resistant tank and rack materials. The results of these evaluations are discussed in this section.

A - Adhesive-Coating of Honeycomb Core:

1. Survey of Existing Methods:

The survey of existing methods, performed at the start of this project indicated that flat honeycomb core materials were being adhesive-coated by a variety of methods, including power roller-coating, hand-rolling with conventional or pressure-fed "paint rollers", spraying, brushing, and "edge-dipping". Where "tapes" were used in the bond, relatively light applications of adhesive were required, and power roller-coating was the most generally used method. Where a "liquid-only" bond was used, the adhesive had to be applied in a relatively heavy "bead" (0.06 to 0.07 lbs. per sq. ft., approximately, both sides) at and above the edges of the cell-walls. Hand-rolling or brushing were found to be the most commonly used methods of applying heavy beads. Power roller-coaters were sometimes used to apply beads, but at least fifteen double "passes" through the machine were usually required to deposit sufficient material. A special method of spraying was sometimes used to apply heavy beads. Here, the surface of the material was first "cobwebbed" over by holding the gun at some distance from the work. The gun was then brought close to the work, and a dense layer of wet adhesive was applied over the cobwebbing. This layer coalesced almost immediately into a "bead" on the top edges of the cell walls. The method was tried experimentally in the project and found to be generally satisfactory, although considerable skill was required to maintain a consistently beaded surface.

Power roller coaters were observed in use in two sandwich-manufacturing plants. These machines were ordinary unhooded "veneer-coaters" of conventional design, usually operated by two men. One man inserted the core slices at the infeed side; the other man removed the slices and handed them back over the machine for the next pass. Although the machines were considered to represent the best

II - A, Continued

production devices available, there were several disadvantages connected with their use. Chief among these was the fact that the excessive handling of the core material tended to remove the wet adhesive locally. Other disadvantages were excessive clean-up time, rapid evaporation of solvents from the stock, hazardous working conditions for the operators, and excessive number of passes required to apply the proper weight of adhesive.

The survey revealed that fabric-reinforced bonds were rapidly replacing liquid-only ("heavy bead") bonds in the industry's preference. Usually, the fabric was added in the form of a cloth-support in a dry film of adhesive. Two major "supported-film" or "tape" systems were in use at the time of the survey. The majority of collected information relating to process variables and physical properties was found to apply to the "FM-47" supported film and liquid system supplied by the Bloomingdale Rubber Co of Chester, Pennsylvania. Because "FM-47" liquid appeared to be typical of metal adhesives as a class, in that its low solvent boiling point, high viscosity, and low solids content represented unfavorable handling conditions, it was used as a test vehicle in coating experiments.

2. Evaluation of the Veneer Coater:

The first stage in this program was an evaluation of a typical "veneer-coater" as a core-priming device. The machine used here was a light-duty, "double" (two side) coater in the low-priced class. The applicator rolls were four inches in diameter and covered with a deep resilient coating of neoprene, smoothly ground. Power was applied through roller chains and gears, from an enclosed 1/4-hp motor. The doctor rolls were mounted on the "in-feed" side of the machine. (See sketch at the top of Table 27 at the end of this discussion, and photograph, Figure 75, at the end of Appendix I.) There was no covering or hood to restrict solvent evaporation. Originally, this machine had been built with the lower doctor roll on the "outfeed" side. Conventionally, most veneer coaters are built in this manner so as to permit use of the angular cavity between the applicator roll and the spreader roll as a reservoir, on both the upper and lower sets of rolls. This machine had been modified by the previous owner to utilize a pan-reservoir system under the lower rolls. The usual "cavity-reservoir" system, with a "seal plate" at each end, was retained in the top rolls.

In the first trial of this machine as a core-coating device, undiluted "FM-47" adhesive was poured in the cavity reservoir between the two upper rolls. The relatively small amount of adhesive in the cavity was subjected to a considerable amount of churning and aeration. Within fifteen minutes, during which time both fresh adhesive and thinner were added, the stock had dried to a point where it was completely unusable. The core material processed in the interim received a very inconsistent, blotchy coating; many of the cells were filled with adhesive, and "cobwebbing" was in evidence. It appeared that the lack of an enclosure to restrict solvent evaporation, in combination with the small reservoir capacity, made it impractical to use the top coating rolls in further work.

In the next trial, "FM-47" adhesive, diluted with an equal part of "FM-47" thinner, was placed in the pan reservoir, under the bottom rolls. Doctor setting, cell size, and the number of passes were adjusted in this run. The unit weights of adhesive to the cores were determined by weighing the cores before they were coated, and after they had received an overnight air-dry, subsequent to coating. The depth of prime down the cell walls was estimated with the aid of a machinist's scale. The weight and depth results are shown in Table 27, at the end of this discussion. Although the primes were relatively consistent and free from cobwebbing and blotching, they were very light in relation to the number of passes which had been applied. The adhesive in the pan reservoir remained reasonably clear and low in viscosity after one hour's operation, but the unit weights tended to increase with time, indicating that a significant loss of solvent was occurring. It was concluded that the use of diluted adhesive reduced the handling problems in coating, but was otherwise uneconomical.

The next runs were made with undiluted adhesive in the lower reservoir. The weights and prime depths observed in this run are also shown in Table 27. The following conditions were observed during the run:

- (1.) There was again some cobwebbing and blotching on the primed surfaces, particularly after the adhesive stock had been used for some time.
- (2.) High circular ridges of adhesive spaced at approximately 1/4-inch intervals were formed on the surfaces of the rolls. These ridges tended to leave heavily primed "stripes" down the lengths of the core slabs, and appeared to cause significant variations in depth of prime.
- (3.) Adhesive tended to crawl steadily out on the roll journals, over the edge of the pan. This adhesive eventually was deposited over the side frames, motor, bearings, gears, and drive chains. The adhesive loss from this flow was of the same magnitude as the amount applied to the core.
- (4.) The loss of solvent from evaporation appeared greater in this run than during the run with diluted adhesive. A heavy odor of solvent fumes surrounded the coater during this run, and after two hours of operation, the workmen felt generally ill from the effects of the fumes. (The toxic and noxious nature of the fumes from the solvents in "FM-47" are not necessarily peculiar to this adhesive; stronger and more immediate effects were sometimes observed in working with other formulations.)

It was apparent that, although power roller-coaters represented the most efficient known devices of applying adhesive primes to large pieces of flat core, special modifications were required to fit them for high production. The following modifications were carried out on the existing machine for evaluation during runs in which quantities of core material were primed for use in other phases of the project:

- (1.) The rolls and reservoir were partially enclosed with sheet metal to restrict evaporation. (A photograph of a fully enclosed commercial machine is shown in Figure 60, at the end of Section II-B.)
- (2.) The speed was reduced from approximately 50 fpm to 25 fpm.
- (3.) The entire unit was placed out of doors as a temporary expedient during coating runs to minimize toxicity and explosion hazards.
- (4.) The standard switch was replaced with an explosion-proof switch. (The motor, although fully enclosed, was not explosion-proof.)
- (5.) Specially contoured "deflector plates" were placed over the journals inboard from the edges of the pan reservoir to reduce tendency for adhesive to leave the pan.
- (6.) A removable expanded-metal safety guard was placed over the top rolls to reduce accident hazard.

Additional runs showed that these modifications had beneficial effects, but that they did not entirely remove the problems of excess fumes and loss of adhesive over the edges of the reservoir. The adhesive still tended to gather in ridges on the rolls, causing relatively heavy, deep streaks on the core material. The core material primed in these runs was not believed to present the desired degree of uniformity for control purposes in experiments dealing with bond strength, but was considered generally representative of core primed for production purposes. It was later determined that the inconsistent depth of adhesive on these cores, a manifestation of the tendency for adhesive to form ridges on the rolls, caused the bonds to be low in strength-weight ratio.

The formation of the ridges was observed to occur at the gap between the doctor and applicator rolls. As the metered adhesive emerged from the doctor gap, it was divided over the two roll surfaces. It did not distribute evenly into two uniform films, but tended to concentrate itself alternately on one roll and then the other, at an even spacing or pitch down the length of the rolls. The concentrated areas tended to be drawn into ridges, the ridges on one roll corresponding to the valleys on the other. As the adhesive grew more viscous from loss of solvent, the spacing tended to increase and the ridges became higher and narrower. Under the most extreme conditions the ridges became as high as 1/8 inch (approximately) and their spacing from each other was approximately 1/2 inch. Ridges as high as 1/8 inch caused prime-depth variations of approximately 1/32 inch.

II - A, Continued

The ridging effect on the rolls and the tendency to apply the liquid in stripes is a common problem in the coating industry. The effect is most pronounced where resinous adhesives are handled, probably because of the high viscosity and/or cohesion of the liquid.

Ordinarily, the ridging problem is relieved on commercial roller coaters by causing the doctor rolls to rotate at a slower speed than the applicator rolls. In order to prevent damage to the roll surfaces in the event of positive contact, the doctor rolls are usually driven through an over-running clutch. In the roller coater used in these evaluations, all of the rolls turned at the same speed and were driven positively. A roller coater having the over-running feature would undoubtedly have given better results, provided that the adhesive was not so viscous that it actually caused the doctor roll to be driven by the applicator roll. Discussions with coating manufacturers indicated that the use of a slow doctor roll, in any event, would not completely remove the striping problem.

It should be noted here that low adhesive viscosity is not necessarily desirable in coating. A viscosity which is too low may cause adhesive to run down the cell walls beyond the optimum desired depth. Similarly, the use of a high-boiling solvent may cause the applied adhesive to run while the primed core is being dried.

3. Experiments with the Hand-Operated Coater; Immersion of Wet Rolls

It was decided to evaluate methods of relieving adhesive roller coating problems on the small, hand-cranked test coater (the same coater used in evaluations of skin-priming variables, discussed in the succeeding section). The roll layout of the smaller machine was generally similar to that of a veneer coater, except that no provision for "top coating" was made. Several runs were made on this machine to prime core material for use in other bond-strength evaluations.

A red dye, "OIL RED 'O'", was added to the adhesive stock in these runs to facilitate inspection of the primed cores. (It is generally recommended that a dye be incorporated in liquid adhesive used for priming. The dye used here may not be optimum for this purpose. The degree of color intensity required in core primes was found to be not as great as that required in skin primes.)

It was found that the weight applied in each pass on the smaller machine was generally lower, and the depth of prime shorter, than had been observed on the larger machine. The cause of this difference was later traced to the fact that the doctor roll on the smaller machine was above the level of the adhesive in the pan, a condition which was due to the particular configuration of the coater, and did not exist in the runs in which facings were coated. Drying of the adhesive on the doctor roll caused the gap to become effectively smaller, reducing the amount metered onto the applicator roll; consequently the amount and depth of the prime on the core was reduced.

(The shorter prime depths applied in this machine were always observed to give generally higher bond strengths at any given set of weight conditions, a fact which confirmed the results of the study of the effect of core prime depth.) It was concluded that both the doctor and applicator rolls should always be immersed in the adhesive stock, if consistent results were to be obtained with adhesives having low-boiling solvents. In effect, this conclusion precludes the use of any system utilizing "transfer-rolls", with low-boiling solvents. The same conclusion was made independently, in the work with sheet-coating equipment, using dilute adhesives.

The adhesive in the hand-driven smaller coater showed the same tendency to form ridges on the applicator roll as it did in the larger machine. The tendency for adhesive to leave the pan on the surfaces of the journals was still observed.

#### 4. Effect of Roll Surface:

In an attempt to reduce the "ridging" effect and apply more adhesive in a single pass, a grooved steel applicator roll was fabricated and tested. The grooves in this roll were semicircular in cross section, 1/32-inches in depth, and spaced at 5/64-inch intervals. No improvement in results was observed. The honeycomb cell walls, in contact with the wet roll surface did not draw the adhesive from the grooves, and appeared to have lighter and shallower primes than those observed on material primed with a smoothly ground rubber-covered roll.

Although the aforementioned evaluation itself did not give sufficient data to form a conclusion as to the effect of roll hardness, the experience with coating equipment accrued in this project has indicated that solid metal rolls would not be suitable for coating core material.

When it is considered that a doctor setting of about 0.020 inch is optimum, and that the closest standard tolerance on commercially available cores is  $\pm 0.005$ , it can be seen that the use of non-resilient rolls would bring about either prime-depth errors, core crushing, or a combination of the two. On the other hand, it is generally known that thick rubber coverings and/or coverings of low Durometer are more subject to swelling and deterioration from the action of solvents. A neoprene of 70 Durometer is generally considered to give the best service with the solvents used in "FM-47". One manufacturer of veneer coaters has ventured the opinion that the best compromise between roll-life and resilience would be offered by a covering of 70-Durometer neoprene, approximately 5/16 inches deep on a roll approximately 8 inches in diameter. These conditions would appear to be reasonable. (It should be noted that most standard veneer coats are offered with coverings approximately twice as deep.) Although two manufacturers have proposed that "gelatin" coverings be used, the contractor has had no experience with this material. It is usually considered advisable to use "relief springs" in the roll mountings to prevent damage resulting to the machine when oversize materials are fed through. In the case of core material, these springs should probably be set at a low pressure setting to prevent damage to the roll surface from the sharp cell-wall edges.

II - A, Continued

In the core-priming work in this project, it appeared that the best method for setting the working clearance or height of the rolls for a given core thickness was to place a small slice of the core between the rolls while the machine was stopped, and bring the rolls together until the core could still be moved about under very low hand pressure without deforming the cells. The core was then re-introduced at several places along the width to check the parallelism of the roll centerlines.

Slippage between the rolls and the core or roll-speed differentials are very undesirable, since they cause excess adhesive to be built up on only one side of the cells.

5. Doctor-Blade Metering:

The next modification, a doctor "blade" in place of the doctor roll, proved to be highly successful. The general layout of this arrangement is shown in Figure 50 at the end of this discussion. Table 28, on the same page, shows weights and depths of prime applied in this manner. The use of a doctor blade rather than a roll as a metering device, completely removed any tendency for the adhesive to form ridges on the applicator rolls. The core primes were almost completely uniform in depth at any given doctor-gap setting. The maximum depth variation was approximately 0.005 inches. The improved consistency made it possible to estimate average depth with reasonable accuracy, whereas this could not be done on material primed in a doctor-roll coater.

In operation, the adhesive was observed to be doctored smoothly and evenly, the excess falling directly back into the reservoir from the gap. As important as the improvement in the consistency of the priming operation was the fact that after one hour of operation, the adhesive in the reservoir was of substantially the same viscosity as at the start of the run. There was no loss of adhesive at the edges of the reservoir, and the odor of the solvents around the machine was far less intense than in previous runs. (The test fixture was not "hooded" for this run.) Evidently, the blade-metering system brought about less evaporation from one or more of the following causes:

- (1.) Only one moving roll was covered with adhesive film.
- (2.) There was no "parting" action in the adhesive at the doctor gap.
- (3.) The smoothly-metered film on the applicator roll presented less surface area than the ridged surface characteristic of other metering systems.

Although it was expected that some dried resin might accumulate on the top and/or bottom of the blade after long operation, there was no wetting whatsoever on the top and only a very light wetting on the bottom, extending for about 1/16 inch from the sharpened edge.

II - A, Continued

The core-prime weights applied in the doctor-blade run (Table 28) were found to be slightly less than those applied in a roll-metered system. The reason for the difference undoubtedly lay in the fact that in the absence of excessive solvent evaporation, the solids content of the blade-metered mix remained substantially the same (approximately 20%) throughout the run. (Higher solids contents were always observed to give heavier prime coats, other conditions being the same.)

The evaluation of the doctor blade had to be performed on 3/16-inch-thick slices of core, because of an unanticipated kinematic problem. The position of the blade was located by a straight, non-rotating shaft, placed in the doctor-roll journal bearings. This orientation permitted the same doctor-gap control to be used on either the blade or the roll. The interference arose from the fact that the blade was mounted too high to permit slabs thicker than 1/4" to pass between the rubber rolls (the sketch does not depict this condition.) For this reason, the blade could not be used in the priming of 0.625-inch core for bond-strength evaluations. Very little core material remained to be primed for the bond-strength evaluation, after the development of the blade principle, so the design of an improved blade-metered fixture for this purpose was not justified. There was no doubt that blade-metering would have resulted in an improvement in bond strength at any given unit weight core prime. The grounds for this conclusion are as follows:

- (1) Shallow primes proved to offer the best strength-weight ratios.
- (2) Where the prime is inconsistent in depth, a major portion of the material would be deposited beyond the optimum (shallow) depth limit, and would not be used efficiently in the bond.
- (3) The blade-metering system allowed the material to be placed at a shallow, uniformly controlled depth.

6. Contacts with Coater Manufacturers:

At this point, letters were sent to a number of manufacturers of coating equipment, giving a description of the blade device and of the results obtained. Shortly afterward, the project engineer visited several of these firms during the tour of eastern and midwestern equipment manufacturing plants. The manufacturers of "veneer-coaters" expressed considerable interest in the blade principle, and indicated that the roll-and-blade configuration used in these investigations had not previously found any use on this type of coating equipment. (The terms "doctor blade", "doctor knife", "scraper bar" and "metering bar" are generally applied to a number of types and configurations of metering and wiping devices used on wet rolls. The conclusions obtained in this project apply only to the configuration shown in Figure 50, as far as is known.)

Most veneer-coating applications do not call for "stripe-free" coatings, and the roll-metering systems in their usual form are normally considered adequate. For this reason, coater manufacturers have not previously felt there was a need for more refined systems. The manufacturers generally agreed, however, that the priming of honeycomb represented a unique problem. It was proposed to the manufacturers that blades could be incorporated in standard veneer coaters by placing straight cylindrical shafts in the bearings intended for the doctor rolls and locating the blade assemblies about these shafts. The original doctor-gap adjustment features could be retained in this manner. Because of the obvious desirability of priming the top sides as well as the bottom sides of the core slabs in the same pass, the application of the blade-metering principle to the top roll was discussed at length. The manufacturers agreed that the proposed method of replacing rolls with blades was generally practical and proposed that, at the top roll, the blade itself could be made the bottom component of a reservoir. The sides of the reservoir would resemble the conventional "seal-plates" used on existing machines, except that they would bear against only one roll and would be bored to receive the locating shaft.

#### 7. Conveying Systems:

The manufacturers of coating equipment were also asked to comment on the feasibility of handling the freshly primed core on a driven conveying system. In response, a system involving driven, knife-edged discs was proposed. Disc conveyors of this type have been used to some extent on flat-surface parts coated on their underside. An experiment (discussed in Section II-B, "Coating of Facings") had previously indicated that knife edge conveyors were not practical for handling adhesive-coated aluminum facings because of their tendency to strip the coating from the surface wherever contact occurred. It was believed, however, that a prime coating on the edges of honeycomb cell walls would not be as subject to stripping because of the intermittent contact of the coated surfaces with the discs, and because of the small area of adhesive contact on the discs in relation to the area of adhesive contact on the cell walls.

In order to test this theory, a number of sharp-edged steel discs were placed on a free-turning shaft, mounted at the outfeed end of the hand-operated test coater. Although the discs, shaft, and other parts became covered with "cobwebbing" there did not appear to be any significant transfer of prime adhesive from the core material to the edges of the discs. Since it was known that the cobwebbing would not occur in a properly designed machine (the fixture used here had the conventional doctor-roll system and was not hooded) it was concluded that a disc conveyor system should be practical for this application. It was further decided that such a system should be equipped with fixed scraper knives on the first few driven shafts to preclude any chance of building up excessive amounts of adhesive on the edges of the discs after continuous use.

II - A, Continued

8. Drying Ovens; Preliminary Design

Since effective means had been developed for uniformly and efficiently applying primers to the cores, and for conveying the wet cores as they emerged from the machine, attention was directed toward the possibility of force-drying the material on the conveyor, so that it could be handled at the end of each pass without danger of removing adhesive. It is generally believed that an oven-dried coating tends to receive a heavier application of liquid in the succeeding pass than does a coating which is still wet, but this theory was not confirmed by experiment. Preliminary calculations were made to determine the venting capacity and heat consumption which would be required in a continuous "tunnel" oven for drying primed core material. These calculations indicated that the oven would have approximately the same configuration and capacity as the continuous curing oven proposed in the continuous coil-processing line, which was under design at that time. It was originally assumed that the core material would travel through the coater and oven at a speed of 35 feet per minute, that the heated length of the oven would be 18 feet, and that a temperature gradient, increasing from 100° to 250°F, would be applied to the material.

In order to duplicate and evaluate these conditions, several freshly primed coupons of honeycomb were placed in a laboratory oven set at 300°F, for 30 seconds. Thermocouples were located in the centers of the coupons and observations were made through a glass in the oven door. Although certain conditions of the test were favorable (the temperature was high, and not in the form of an increasing gradient) the conditions as a whole were considered unfavorable in that the honeycomb was not consistently coated (much of the adhesive was concentrated in local areas) and the air velocity within the oven was relatively low. The temperatures within the honeycomb coupons were observed to rise uniformly and reach a maximum of approximately 240°F within 25 seconds on all the specimens, including some which received additional coats of adhesive after successive drying cycles.

Visual observation revealed that solvent in the denser portions of the coating began to "boil" after about 15 seconds (180°F, approximately) but that the boiling stopped after the 25 seconds had elapsed. An inspection of the dried surfaces after removal from the oven indicated that the bubbles no longer existed in the areas in which boiling had occurred; the adhesive had coalesced completely into a relatively dense, homogeneous mass. The coating appeared generally dry, and was not tacky. It appeared that the drying conditions imposed here would have been generally adequate to prepare freshly primed core for handling and for successive additional roller-coating passes. There was no doubt that the conditions were favorable when compared to conditions in which the wet core is removed from the coater by hand and given another pass after a very short air dry.

### 9. Preparation and Distribution of Proposed Specifications

The conclusions and results of the evaluations dealing with the priming of core material were compiled in "Proposed Specification 'S-5' For Mechanized Core-Priming and Drying Line". (See Appendix V). A schematic drawing of the line (C-3) and a drawing showing the proposed method of modifying standard veneer coaters for core priming (C-4) were included. The text of the specification included a general description of the process requirements, pertinent observations on desirable and undesirable features, and a set of sample calculations dealing with heat capacities and air rates in the oven.

Copies of "Specification 'S-5'" were distributed among manufacturers of coating and oven equipment for comments and approximate cost estimates. The following is a listing of manufacturers who acknowledged receipt of the letter, and indicated that they could supply portions of the equipment required for the coating and drying of honeycomb core material. (This list does not constitute an endorsement of the qualifications of these firms, and undoubtedly overlooks some firms who are qualified to supply this equipment.)

#### Coating Machines:

Black Brothers Co., Inc.  
503 Ninth Avenue  
Mendota, Illinois

Potdevin Machine Co.  
200 North Street  
Teterboro, New Jersey

Union Tool Corp.  
Warsaw, Indiana

John Waldron Corp.  
P. O. Box 791  
New Brunswick, New Jersey

#### Oven and/or Conveying System:

Aladdin Heating Corp.  
111 West 137th Avenue  
San Leandro, California

Drying Systems, Inc.  
1808 W. Foster Avenue  
Chicago 40, Illinois

Young Bros. Co.  
1831 Columbus Road  
Cleveland 13, Ohio

W. C. Matheson Co.  
228 - 9th Street  
San Francisco, California

Grieve-Hendry Co., Inc.  
1811 West Lake Street  
Chicago 12, Illinois

Ovens for Industry, Inc.  
2032 West 105th Street  
Cleveland 2, Ohio

Industrial Ovens, Inc.  
13825 Triskett Road  
Cleveland 11, Ohio

J. O. Ross Engineering Corp.  
600 St. Paul Avenue  
Los Angeles, California

The coating manufacturers who specialize in veneer-coating equipment indicated that no major revisions were considered necessary in the design of the "doctor-blade" coater. The range of their estimates indicated that a suitable machine could be procured for a price of the order of \$2,500.00 under competitive bidding conditions.

II - A, Continued

Oven manufacturers voiced some opposition to the proposed configuration of the oven. (The configuration was not offered as a firm recommendation.) It should be noted that a few of the configurations offered as alternatives appeared to be obviously impractical in themselves. The oven manufacturers generally agreed that the length of the heated portion should be increased from 18 feet to approximately 24 feet, to simplify the temperature-control problems. They further pointed out that the original estimate of the heat input was in error, in that it neglected the BTU's required to heat the core material itself. An important and apparently valid criticism of one of the basic assumptions, on the ovens in both the core line and the coil line, was offered by one manufacturer of continuous-coil lines. The water vapor produced as a product of combustion in a direct gas-fired heat exchanger is likely to condense into the coating as a result of the difference in temperature between the work and the surrounding air. This observation would appear to be applicable to any type of oven in which adhesive coatings are applied, and would make the use of an indirect-fired unit mandatory for use with and bonding system that was susceptible to strength loss from the absorption of water.

An analysis of the comments and estimates received from the oven manufacturers indicated that the conveyors, oven housing, and heat exchanger(s) could be purchased at a price of the order of \$15,000.00.

Final proposals on this type of equipment would require some scrutiny to determine if fully practical systems were being offered by every manufacturer.

The comments and criticisms received from manufacturers in regard to "Specification S-5" were used in preparing a "Supplement" containing notes which supersede the information in the original specification, where applicable. Both the original specification (with minor corrections included) and the supplement appear in Appendix V. It must be emphasized that this specification material is not intended to be formal, rigid, or binding and was prepared only to serve as a guide in the intelligent selection of equipment by manufacturers and users. It should be noted that "Proposed Specification S-5" is not a Government specification.

10. Cost Savings from Improved Methods:

It is estimated that the cost of priming and drying flat core material can be reduced to approximately half the cost of current methods assuming full-shift operations in either case. It is assumed here that the current method utilizes a conventional "two-side" veneer coater, batch ovens, and no intentional drying time between passes. The crew in each case would be the same, but less time would be required for each pass in the proposed method, since the parts could be fed in an almost unbroken series, and the racking time for drying would be eliminated. Amortization cost would be significantly lowered because of the efficient oven utilization. Cleanup time would be significantly reduced, and the consumption of thinner in replacing evaporated solvents would become negligible. The improved consistency of prime depth would permit lighter primes to be applied without sacrificing bond strength. The scrap loss and/or rework costs resulting from the removal of wet adhesive in the handling of undried parts would be eliminated.

## II - A, Continued

The total saving in the cost of priming core material resulting from improvements in methods, including the savings realized by more efficient utilization of adhesive in the bond, would be of the order of five cents per square foot. This figure does not include savings that would be indirectly realized from reduced rejection rates and lowered inspection costs as a result of improvements in consistency of quality.

### II. Conclusions

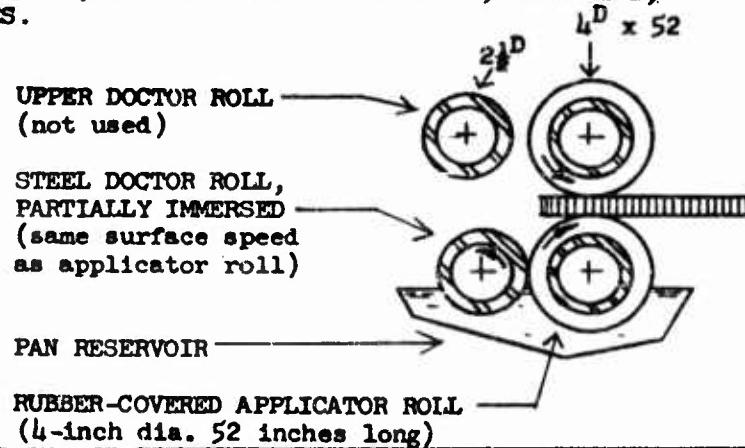
- (1.) A plain, unmodified roller coater of the type known as a "veneer coater" can be used to apply primes of viscous, resinous adhesives to flat honeycomb, but the following disadvantages apply to its use.
  - (a) Ordinary "doctor-roll" metering causes the adhesive to form in ridges on the rolls, resulting in deeply primed "stripes" on the work.
  - (b) The roll-metering system and the usual lack of enclosure cause excessive solvent loss, resulting in dangerous and unhealthy conditions, changes in coating characteristics, and loss of adhesive over the roll journals.
  - (c) Large, freshly coated parts cannot be handled easily without removing adhesive in local areas.
  - (d) The conventional "roll-cavity" reservoir system causes excessive churning and aeration of the mix, resulting in very rapid increases in viscosity from evaporation of solvent.
- (2.) One type of "doctor-blade" metering system presents overwhelming advantages over the roll-metering system in that the depth of prime is held very consistently and solvent loss is reduced. Most types of veneer-coaters can be modified to use this system.
- (3.) Grooved applicator rolls offer no advantages over smoothly ground rubber-covered rolls.
- (4.) Applicator-roll surfaces should be resilient enough to permit contact with the work to be established, without danger of damage to either the roll or the work, should the parts be slightly over thickness. Overly resilient rolls are probably more susceptible to swelling by the solvents.
- (5.) It appears to be feasible and economical to dry primed honeycomb in the same operation in which it is coated.
- (6.) In any coating system used with low-boiling solvents, all wet rolls should be immersed in the stock solution and a sheet-metal enclosure should be used to retard evaporation. A photograph of an enclosed machine is shown in Figure 58 at the end of Part B of this section.

TABLE 27

WEIGHT AND DEPTH OF "FM-47" LIQUID ADHESIVE APPLIED TO ALUMINUM HONEYCOMB CORE MATERIAL IN UNHOODED POWER ROLLER COATER, AS A FUNCTION OF DILUTION, CELL SIZE, DOCTOR SETTING, AND NUMBER OF PASSES.

## Note:

These results are not representative of a machine which is properly enclosed to restrict solvent evaporation, or of one in which metering is accomplished with a blade.



Dilution	Doctor Setting Inches	Number of Passes*	Wt. of Adhesive in Lbs./sq. ft. on both sides of honey- comb cut .625" thick after 2-day air dry.				Approx. Depth of Prime Inches	Remarks
			1/8" Cell	3/16" Cell	1/4" Cell	3/8" Cell		
Diluted with FM-47 thinner, 1:1.	** .030 ±.010	2	.002	.002	.001	.000	.010 to .020	Good distribution
		4	---	---	.002	---		
		6	---	---	.004	---		
		10	---	---	.006	---		
	.050** ±.010	18	---	---	.014	---	.020 to .035	Uniform
		2	.006	---	.006	---		
		6	.014	---	.010	---	.050 to .065 (.040 to .050 for 1/8 core)	Uniform, Bubbles
		Wide Open	2	.034	.026	.022	.012	
Diluted 1:1, used in coater for 1 hr.	.040	2	.012	---	.006	---	.025 to .040	Uniform, Clear
Undiluted	.030	1	.003	---	.002	---	.010 to .040	Blotchy, Streaks, Cobwebbed.
		2	.012	.010	.010	.005		
		4	.024	---	.020	---		
		6	.034	---	.024	---		
		10	.062	.046	.034	.032		
	.050	2	.020	.016	.012	.012	.020 to .040 (.015 to .035 for 1/8 core)	Blotchy
		4	.036	---	.020	---		
		6	.046	---	.026	---		
		10	.086	.062	.060	.044		

\* Direction of core reversed for each pass.

\*\* Doctor roll was later found to be warped .010 inches out of concentricity. Other runs were made after a straight roll had been substituted.

Figure 50  
SKETCH OF CORE-PRIMING TEST FIXTURE WITH DOCTOR-BLADE METERING SYSTEM

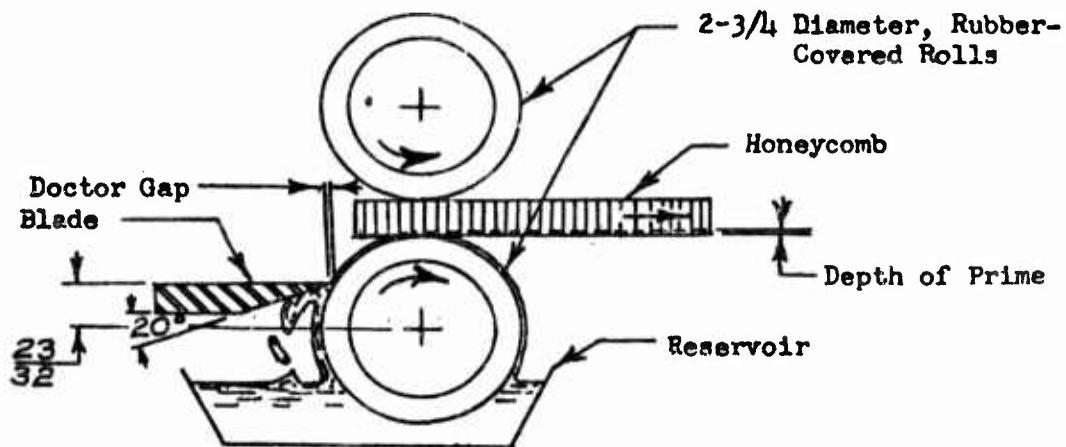


Table 28

DEPTHS AND WEIGHTS OF UNDILUTED "FM-47" ADHESIVE APPLIED TO HONEY-COMB CORE MATERIAL IN COATING FIXTURE HAVING DOCTOR-BLADE METERING

Doctor Setting Inches	Number of Passes (each side)	1/8-inch Cell		1/4-inch Cell	
		Air-Dried Unit Weight (both sides) lb/sq.ft.	Depth of Prime Inches	Air-Dried Unit Weight (both sides) lb/sq.ft.	Depth of Prime Inches
.015	4	--	--	.003	.012
	6	--	--	.005	"
.020	4	--	--	.008	.015
	6	--	--	.010	"
.030	1	--	--	.005	.020
	2	--	--	.008	"
	4	.015	.020	.011	"
	6	.031	"	.017	"
	8	--	--	.021	"
	12	--	--	.043	"
	2	.018	.025-.030	--	---
	6	.070	"	--	---

SECTION II, Continued

B - DEVELOPMENT OF COATING METHODS FOR FACINGS IN THE SHEET AND COIL FORMS:

The results of the "survey of existing methods" did not disclose any practical experience on the part of sandwich manufacturers in the roller coating of aluminum sandwich facings, with metal adhesives. Survey results indicated that the most popular method of applying primers to the facing was by spraying. The only other commonly used method was brushing. The highest degree of mechanization observed in the survey was where cleaned facing sheets were placed on a moving conveyor and passed through a spray booth. A sheet of continuously moving Kraft paper covered the conveyor and protected its mechanism, as well as the backs of the sheets, from the manually directed spray. Although the roller coating of individual sheets had been tried by various firms, no practical means of keeping the backs of the sheets free of adhesive had been found. The investigations of coating methods in this project, discussed in this section, did not reveal any practical methods of coating one side only of thin, individual sheets, but indicated that the coating of continuous strips was feasible.

The first major experimental effort in the roller-coating of facings in this project was directed toward the development of a successful coater for single sheets. Although there was some doubt whether a practical method existed, it was felt that most of the data and experience gained in this effort could be used in the development of a coating system for continuous webs, whether the single-sheet coating development was successful or not.

It was decided to use dilute "FM-47" liquid in all roller-coating experiments on facings. This formulation was chosen because of its general use as a supported-film and liquid system in sandwich bonding, and because its high viscosity, low solids content, and low solvent boiling point provided unfavorable conditions for coating which are typical of metal adhesives as a class. In order to give reference data, several facings were primed with one, two, and three brush coats of dilute "FM-47" and dried. The following is a tabulation of the unit weights and coating thicknesses observed in this study:

Number of Brush Coats	Average Unit Weight Lbs./Sq.Ft.	Average Thickness Inches
1	0.0013	0.0002
2	0.0038	0.0007
3	0.0079	0.0012

During one of the early core-priming runs in this project, conducted on the power veneer coater, several 0.016-inch-thick facings were passed through experimentally. A number of these facings were "backed" with starch-bound "FIBERGLASS surfacing mat" to increase their effective thickness to approximately 0.025 inch. The backed sheets were coated successfully, but the gap between the wet and dry rolls could not be set to accommodate the unbacked sheets without the danger of adhesive transfer. Backing the sheets was considered impractical for production because of a tendency for glass fibers to remain on the aluminum after the mat was stripped off.

II - B, Continued

The fundamental problem in coating one side only of a thin sheet of metal lies in the fact that the gap between the wet "applicator roll" and the dry "backup roll" is small, allowing adhesive to transfer from one roll to the other. It was believed that if the single backup roll could be replaced by two smaller rolls, offset from the centerline, the effective gap between the wet and dry rolls could be increased while still maintaining sufficient backup pressure to keep the surface of the sheet in full contact with the applicator roll.

A special hand-operated test coater (see Figures 51 and 52, and Drawing P-1 in Figure 53, at the end of this discussion) was built to evaluate the "double backup roll" principle. As can be seen in Drawing "P-1", the two small-diameter rubber-covered backup rolls were driven by a common idler shaft. The axis of this shaft passed through bearings, which were located in such a way that a single, large-diameter roll could be substituted for use in other coating experiments, on either core or facings.

In the first two experiments with this machine, all the rubber-covered rolls were left smoothly ground. The pan reservoir was charged with "FM-47", diluted with an equal part of "FM-47" thinner to give a solids content of the order of ten percent. Undiluted adhesive at 20 percent solids was found to be too viscous for this type of coating.

In the first run, the coater was used alone without the auxiliary conveyors shown in the drawing and photographs. The doctor gap was varied from 0.005 to 0.010 inches. Aluminum sheets, ten inches wide, eighteen inches long, and 0.012 to 0.040 inches thick were tried in the machine. The average unit weight of the coatings was found to be approximately 0.0006 lbs. per square foot. Although the coatings appeared generally uniform, the degree of coverage could not be satisfactorily determined because of the lack of dye coloration in the adhesive. It was apparent, however, that about 1/4 inch on the leading edge of each sheet had been left unprimed, while the back edge received a heavy deposit which sometimes extended around to the top (uncoated) side of the sheet. As the back edge of the sheet left the machine, adhesive from the wet roll sometimes splashed onto the dry backup rolls.

In the second run the "infeed" and "outfeed" conveyors shown in the photographs and Drawing P-1 (Figure 53) were added, and the entire machine was tipped at a three-degree downward incline. These modifications were intended to guide the sheet in and out of the machine and to keep it moving as it emerged from the rollers. A dye ("OIL RED O") was added, to the adhesive to aid in determining the completeness of the coating. The width of the unprimed area was found to be reduced, and the tendency for adhesive to get on the backs of the sheets was eliminated by these modifications, but adhesive still tended to transfer from the wet rolls to the dry rolls. It was apparent that the coating was inconsistent, and that some bare spots were present, particularly on thinner gage materials. The knife-edged discs on the outfeed conveyor were found to have stripped the coating entirely away wherever they contacted the sheet. During this run, the effective gap between the applicator roll and the backup rolls was varied in an attempt to improve the completeness of coverage, without success.

Although the double-backup-roll coating system appeared to have doubtful practicability, it was decided to make at least one more test. It was believed that the poor distribution of the coating might have been due to insufficient resilience in the backup rolls.

The tendency to wet the backup rolls as the sheets left the machine appeared to result from the entrapment of an excess of liquid between the sheet and the roll. This condition could be relieved by "grooving" the rubber applicator roll, according to accepted practice in the coating industry.

It appeared that a special "outfeed" conveying system was necessary to handle sheets without touching the bottom (wet) side. The special "inverting" conveyor system, shown in Drawing P-2 (Figure 54) was built to fulfill this requirement. Other modifications noted on Drawing P-2 are a helically-grooved, rubber applicator roll, and a special set of "O-ring" covered backup rolls. The purpose in using "O-rings" in preference to a solid rubber covering was to provide a highly elastic surface without the need for using rubber of low Durometer.

Strips of cleaned aluminum, 0.012 to 0.051 inches thick and from four to six inches wide, were experimentally primed in the test model shown in "P-2". A deep red coloring was added to the adhesive to facilitate inspection. Several of the strips received smooth, uniform coatings in these tests, but the results were found to be generally unpredictable. Some strips showed bare streaks corresponding to the pattern of the grooves on the applicator roll. In general, the coatings were found to be uniform when a doctor-gap setting of the order of 0.015 inches was used. It was further discovered, however, that the tendency for adhesive to collect under the sheets and eventually transfer itself to the dry rolls, still remained, and that the condition appeared to exist at doctor settings in excess of 0.010 inches. The two conflicting doctor-setting requirements appeared to make the double-backup-roll coating system fundamentally impractical. In order to confirm these conclusions, it was decided to try the system with a "doctor blade" (the same one used successfully in experiments on honeycomb core) in place of the doctor roll. Although the blade removed the tendency for the adhesive to form "ridges" on the wet applicator roll, there was no other apparent improvement in results.

The "O"-ring"-covered backup rolls appeared to have been a desirable and practical improvement, but they offered no further utility in the project, because of the basic impracticability of the individual sheet coating system. The inverting conveyor system worked reasonably well on the lighter gages, and probably could have been made fully practical by adding additional rollers at a closer spacing in the curved portion. Since the roller coating of individual thin-gage sheets appeared generally impractical, no further development was carried out on the special conveyor.

In the course of the work with helically grooved rubber rolls, a tendency for the sheets to "track" to the side was observed. Discussions with engineers familiar with strip-tracking problems revealed

that driven, helically grooved, rubber rolls cause the sheet to track in the direction opposite to the apparent lateral motion of the lands at the line of contact, because of a tilting or buckling of the lands as they come in contact with the web.

Very little information in regard to individual-sheet coaters for thin gages was received in response to the survey of equipment manufacturers. Several firms have experimented with various techniques in past years, but no fully practical system has been resolved. One of the latest methods tried is an "intermittent" coating system, in which the pressure rolls are held apart until microswitches or photoelectric devices sense the approach of the sheet. An uncoated margin, approximately 1/4 inch in width, must be tolerated around the entire edge of the coated surface for the successful operation of this system. In general, it appears that individual sheets thicker than (approximately) 0.020 inches can be primed on one side in conventional veneer-coaters, but that no fully reliable system for coating one side of cut sheet material thinner than 0.020 inches exists.

Further experiments were carried out on the hand-operated coating fixture to develop methods for coating continuous webs. Since the failure of the individual-sheet machine was thought to be due primarily to a lack of positive backup-pressure, the two small backup rolls were replaced by one large-diameter roll. Long individual strips were used in lieu of continuous webs. The spring-loaded rolls were held open while the web was inserted, and were sprung open again as the end of the strip left the machine. With the spreader roll helically grooved to the dimensions shown on Drawing "P-2", and with a doctor setting of "zero", the coating appeared to be complete over the surface, but it was very light, and the pattern of the helices was in evidence. The back-up roll was wetted from adhesive transfer at the edges of the sheet only. This transfer caused the "dry" side of the sheet to be very lightly stained with adhesive to a depth of approximately 1/16 inches from its edges. It was believed that a revision of the grooving configuration might relieve the problem.

At this stage in the development of this type of "grooved-roll" coating device, it was decided to make a run under simulated production conditions in a foil-processing line. A quantity of 3S-HL4 coiled sheet, 0.010 inch thick and eight inches wide, was procured for this purpose. The two basic objectives of the "continuous-web" run were as follows:

- (1) Determine the feasibility of continuously coating the web on one side only in an undriven system utilizing a rubber applicator roll, helically ground to a "herringbone" pattern. The grooves in this roll were of larger area than those used in previous experiments. (The purpose in using the herringbone configuration was to give a self-centering effect which would insure good tracking.)

II - B, Continued

- (2) Determine the feasibility of continuously laminating a web of paper-backed polyethylene to the primed surface of an aluminum web under heat and pressure. (It had been found practical to laminate these materials in a hot press, and it appeared to be advantageous to perform this lamination on a continuously-processed web to provide protection, as well as a surface which would lend itself to identification stenciling.)

A schematic drawing of the test setup is shown in Figure 55. Photographs of the coater and interleaver and of the cleaning tanks are shown in Figures 57, 58 and 59 at the end of this article. It will be noted in Figure 55 that a "slit-rubber roll" was used in the interleaving assembly, and that a "narrow-bodied" roll was used ahead of the coater. The "slit" roll is a patented type, used to achieve a self-centering effect. It was not evaluated for this purpose, but was slit only to simulate the actual surface condition which would be found under production conditions. The "narrow-bodied" roll was added to relieve an anticipated "tracking" problem at the coater. The operation of these special rolls is discussed in Part D of this section.

In the performance of this run, the web showed no tendency to "track" or "weave" when no interleaving was being performed. It is not known whether tracking error might have occurred if the "slit" roll and/or the "narrow-bodied" roll had not been used. As soon as the paper-backed polyethylene was introduced, and the roll pressure was applied, the centerlines of the two webs began to diverge noticeably, beyond the interleaver. Although some adhesion between the interleaving material and the primed web probably occurred at the pressure rolls themselves, the two webs were found to have been completely delaminated after they had passed over the next roll in the system. Part of the difficulty in continuously laminating these two materials was probably due to a difference in their coefficients of thermal expansion. Continuously laminating at this stage in the process appeared to be impractical. It is possible that the lamination of plain, unbacked polyethylene would be practical in such a process, if performed between hot "nip" rolls at, or very near, the "rewind" stage.

The coating method evaluated here also appeared generally impractical. It was apparent that a "squeeze-roll" coater in such a system could not be driven by the web alone, because of the lubricating effect of the adhesive. It was necessary to add a temporary hand crank to the applicator roll to supply enough additional torque to prevent slipping. It appeared that this coater, like the earlier "double-backup-roll" coater, had conflicting doctor-roll setting requirements. With the 0.010-inch-thick strip, the setting had to be very nearly zero to prevent wetting the backup roll. This setting, in turn, did not supply a sufficient amount of adhesive to the surface of the applicator roll to uniformly cover the surface of the strip. In order to apply a coating of reasonable thickness and uniformity, the doctor setting had to be opened to a degree which caused the backup roll and the clean side of the strip to be wetted. The best results were obtained at roll pressures in excess of 100 lbs., as measured by the spring scale.

It should be noted at this point that grooved applicator rolls are generally considered to be superior, as a coating medium, to smoothly ground rolls, and that two manufacturers of coating equipment indicated that the magnitudes of the groove dimensions used on the experimental rolls in this project were in the correct range. It has appeared that metal adhesives such as "FM-47" present coating problems which are basically different from those encountered with more conventional materials, and do not lend themselves to application from grooved rolls. A possible explanation for this difference is that the adhesive, in a liquid form, has less affinity for the aluminum sheet than for the sides of the grooves in the rubber roll.

A further criticism of grooved rubber rolls, which came forth in this experiment, was the fact that grooved rolls appeared to be far more susceptible to attack by the solvents than smoothly-ground rolls. When the "herringbone" roll was removed after the run, and rubbed down with a solvent-dampened rag, some of the groove lands were torn away. Although smooth neoprene rolls often show a significant swelling from the action of the solvents in "FM-47", they are not subject to such complete deterioration, probably because they present less surface area for the absorption of solvent.

The poor performance of grooved rubber applicator rolls in this experiment appeared to rule them out. One further experiment was conducted on a squeeze-roll coater having smooth, resilient rubber rolls. As in the first coating experiment, conducted on backed and unbacked sheets, 0.016-inches thick, the powered "veneer coater" was used. The objective of the later experiment was to determine if it might be practical to squeeze 0.010-inch webs under such a high pressure that adhesive would not be able to flow over the top edges of the webs, under conditions where the backup roll was completely wetted with transferred adhesive. The test indicated that higher squeeze pressures increased the tendency for adhesive to "crawl" onto the dry side of the sheets. On the other hand, higher pressures improved the uniformity of the coating. Doctor-gap setting was observed to have very little effect, in this run. It was apparent that the quality of the coating obtained with the use of smoothly ground rubber rolls was superior to that obtained from grooved rolls, contrary to opinions held in the coating industry. The earlier experiment with the "squeeze-roll" system indicated that the lower limit of metal thickness which could be successfully coated on one side was of the order of 0.020 inches. The limit would be lowered where either roll pressure or the resilience of the roll surfaces was increased.

Concurrent with some of the later investigations of grooved rolls, research was being performed on a fundamentally different type of coating system, the "reverse-roll" method. In the same foil-processing machine used in the coating and interleaving experiment, a quantity of 3S-H19 foil, 0.006 inches thick and 39 inches wide, was coated over the entire surface of one side with "FM-47" in the coating system shown schematically in Figure 56. (It should be observed that no backup roll was used here.) There was no tendency for the adhesive to "crawl" around the edges of the web. The coating was uniform and satisfactory (superior to that observed on the material coated in the smoothly ground "squeeze-roll" system). After a long period of operation, the coating

II - B, Continued

began to show bare areas. This difficulty was traced to drying of the adhesive on the applicator roll. The use of an unsubmerged roll, as shown in Figure 56, with an adhesive having "low-boiling" solvents is inadvisable. All rolls should be submerged as far as possible in the reservoir stock to prevent changes in coating conditions resulting from solvent evaporation. As an additional precaution, the rolls and reservoir should be enclosed to retard the evaporation of solvents. (It may be noted that, under the conditions of the experiment, it was not possible to submerge both rolls without losing the effect of the doctoring. With the web passing straight downward, or at any downward slope, it is impossible to submerge both rolls and still be able to meter the surface of the applicator roll in a reverse-roll system.)

While the metering of the adhesive onto the applicator roll is performed by a doctoring system in reverse-roll coating, the metering of the adhesive onto the strip from the roll is a function of reverse speed, as well as doctor setting. Faster roll speeds give a heavier deposit on the strip from a relatively thin film of adhesive on the roll. It should be noted that reverse-roll systems have recently found favor in the continuous painting of cleaned aluminum strip for metal awnings and other precoated assemblies. The chief advantage of the system is its ability to apply a uniform, stripe-free coating. The formation of stripes or ridges on rolls from the cohesive action of the liquid was discussed in Part A of this section. Stripes were not observed on the foil which had been experimentally reverse-roll-coated.

It appears that the reverse-roll coating method would be entirely suitable for the thinner gages, but its practicability on heavier gages (above 0.025 inches) would be doubtful unless some auxiliary means were available for backing up the web, to flatten out heat-treatment warpages and rolling irregularities. A positive backing is not objectionable with the thicker gages, since the clearance between the dry and wet rolls is sufficient to eliminate the danger of wetting the dry roll. In continuous paint coaters (see Figure 68 in Part D, Section II) the web is usually positively backed and flattened where it contacts the applicator roll, by passing it around a precisely ground drum while under tension. (These coaters are not ordinarily used on webs thinner than 0.020 inches because of a lack of demand for such light material.) With high reverse-roll speeds, it is possible that the thickness of adhesive on the applicator roll in such a system can be reduced to the point where webs as thin as 0.008 inches may be coated without danger of transfer to the backup drum, making it possible to use only one coating system for all gages. The actual lower safe limit of web thickness in such a system would be determined by the precision of construction of the particular machine in question, and cannot be evaluated on a different machine.

Since a reverse-roll coating system must usually be supplied without a backup roll or drum, it is necessary that two coaters be specified in a continuous strip system which is to handle heat-treated aluminum in the range of thickness between 0.008 and 0.040 inches. A "reverse-roll" coater would be used on gages up to 0.020 or 0.025 inches. A squeeze-roll system, or an additional reverse-roll

II - B, Continued

system with a backup roll, would be used on thicker materials to obtain complete coverage on warped webs, without the need for applying high strip tensions. The probable need for two coating systems has been mentioned in "Proposed Specification 'S-4'" which appears as Appendix IV of this report.

The last experiment relating to the continuous coating of webs performed in this project was a determination of the need for the introduction of an "interleaf" or "separator sheet" to prevent finished primed aluminum coils from "tacking" together under storage. Originally, Proposed Specification "S-4" called for the introduction of a polyethylene web at the rewind stage to prevent adjacent surfaces from tacking together, and to provide extra protection during handling and exposure. A cost analysis revealed that the polyethylene would add 0.7 cents to the cost of processing each square foot of aluminum, whereas the total cost of cleaning and priming was of the order of 4 cents. Previous experiments had proved that it was impractical to provide enough lamination to keep the polyethylene firmly attached to the primed surface throughout subsequent shearing and handling operation, so its value as a protective covering was restricted. One remaining justification for an interleaf which had not been evaluated was its ability to prevent adjacent loops of primed aluminum coils from becoming adhered together during storage. It was decided that the seriousness of this problem should be investigated to determine if the interleaf could be neglected.

Since it was not possible to evaluate the effects of pressure (from dead weight) and temperature on actual coated coils, it was decided to press individual primed sheets together in a laboratory press under an unfavorable set of conditions. A number of strips of alclad 24S-T3 aluminum, 0.016 inches thick, were cleaned by the control methods and brush-primed with "FM-47" to a dried weight of approximately 0.002 lbs per square foot. The coating obtained in this manner was relatively inconsistent in thickness, and contained localized areas which were so thick as to be difficult to dry out. The wet material was placed in a laboratory oven at 300°F for one minute to give unfavorable drying conditions. The strips were then stacked in three groups of three strips each, with the primed side of one strip bearing against the unprimed side of the next strip. A piece of Kraft paper was placed against the last exposed primed surface in each stack. These stacks were placed in a hot-plate press with a generous amount of padding material at a pressure of 200 psi (assuming a 48-inch-wide coil, 5000 lbs. in weight, lying on its side, and supported by an area 1/2 inch wide and 48 inches long), for one hour, at temperatures of 70°, 115°, and 150°F.

At 70°F, there was found to be no lamination or "tack" between the bare aluminum and the prime, or between the paper and the prime. At 115°F, the primes were observed to have adhered to the clean aluminum over about five per cent of the surface. Where this adhesion occurred, the prime had been stripped away from its original surface. The degree of adhesion was very low and the surfaces could be separated easily. The paper adhered tightly to the prime in this set of specimens, however. The specimens pressed at 150°F were tightly adhered together, and about 20% of the adhesive was transferred. The paper was completely bonded to the adjacent primed surface.

II - B, Continued

Since the experimental conditions under which adjacent, primed sheets became adhered to each other were very unfavorable, it was concluded that a polyethylene interleaf would not be needed if reasonable conditions of manufacture and storage were observed. These conditions would be:

- (1) Reasonable consistency of coating thickness,
- (2) Final oven pre-cure temperatures not to be below 325°F,
- (3) Storage of the coated coils at temperatures below 90°F.

Kraft paper appeared to be entirely unsuitable for use as a protective covering on primed surfaces.

Conclusions:

The following are the general conclusions obtained from the studies of manufacturing variables in the application of adhesive primes to the surfaces of aluminum sheet:

(1.) There is no known, practical method of applying adhesive to one side only of individual sheets thinner than 0.020 inches (approximately) by power roller coating.

(2.) All roller coating systems in which low-boiling solvents must be handled should be enclosed to restrict solvent evaporation, and all wet rolls should be partially submerged in the coating solution.

(3.) The use of grooved applicator rolls in the roller coating of adhesives such as "FM-47" does not give good results.

(4.) The most uniform and complete coatings can be applied to light-gage, continuous aluminum webs by the use of a reverse-roll technique.

(5.) A reverse-roll technique cannot be expected to work satisfactorily on heavy-gage webs containing warpages and other discontinuities unless the material is backed up by some means, such as wrapping it around a solid drum. The presence of a backup roll or drum makes it difficult to coat one side of a very thin web without transferring adhesive from the wet roll to the dry roll.

(6.) Satisfactory coatings can be applied to one side of individual sheets or continuous webs thicker than 0.020 or 0.025 inches (approximately) by the use of smoothly ground resilient surfaced rolls which exert a "nip" or "squeeze" pressure on the web.

(7.) If reasonable conditions of manufacture and storage are observed, it is not necessary to add polyethylene or other non-adhering material as a coil interleaf, to prevent dried "FM-47" primed surfaces from becoming adhered to adjacent bare aluminum surfaces. In the event both sides were coated, interleaving would become mandatory.

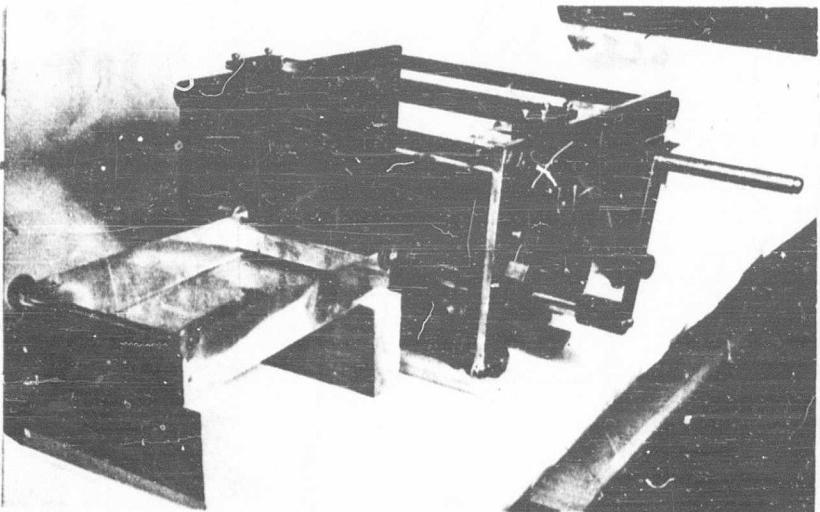


Figure 51. "Infeed" end of coater, with conveyor in place. Note shims under frame, giving 3° incline. Floating frame at top carries two backup rolls and idler shaft.

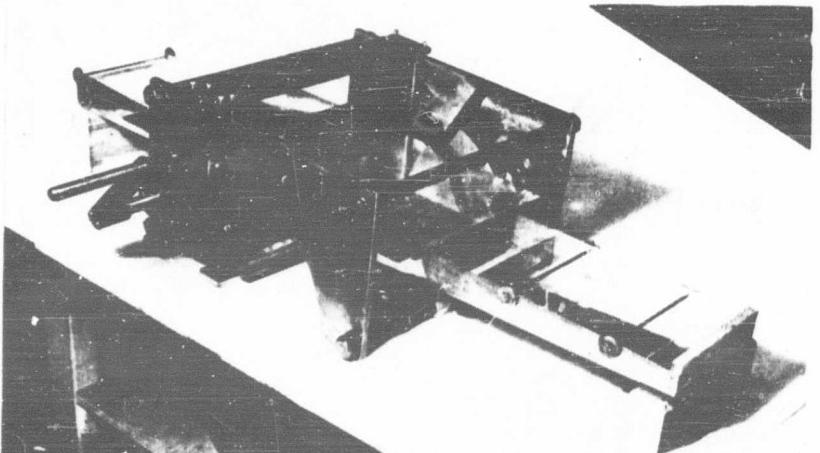
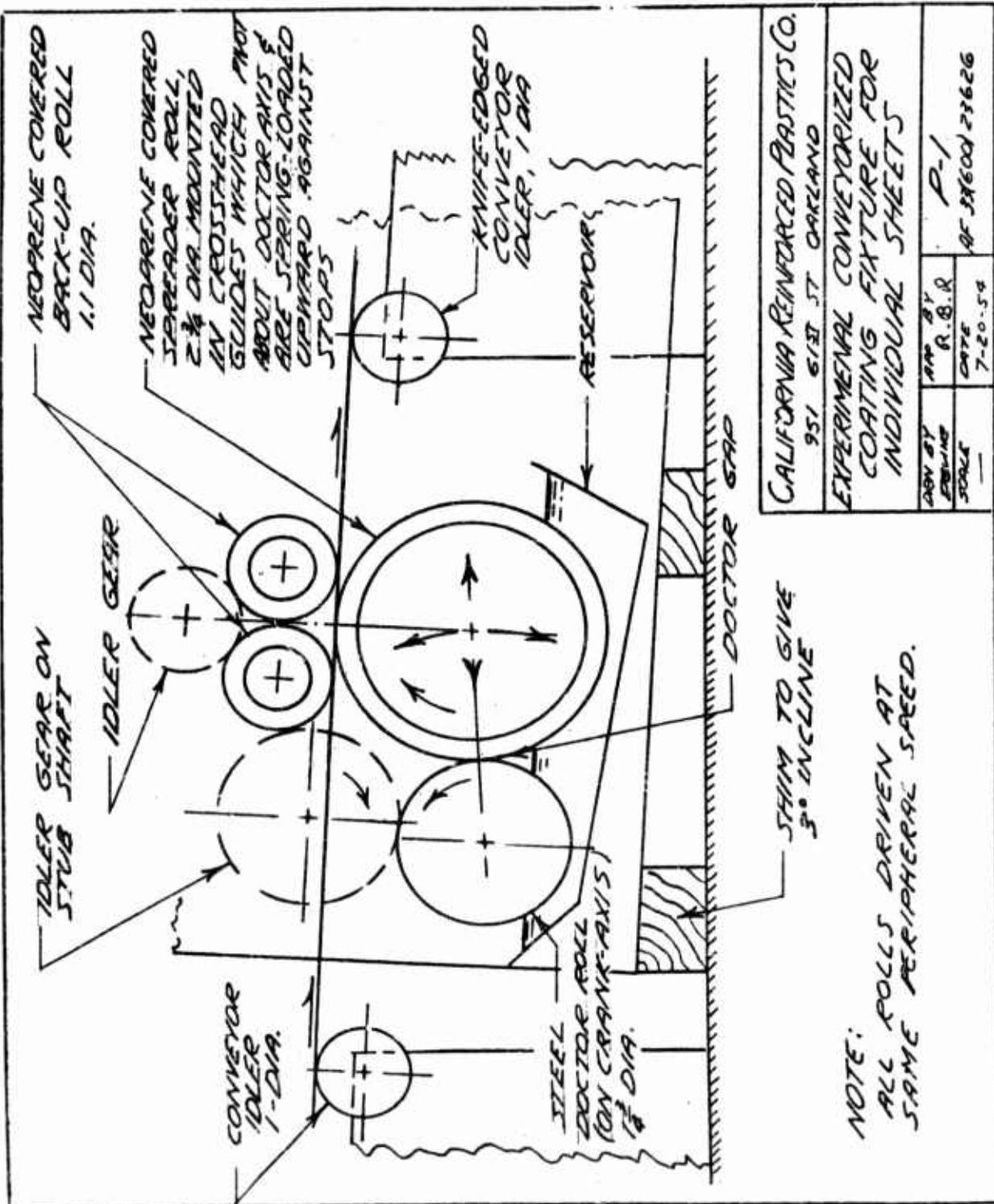


Figure 52. "Outfeed" end. Note 10" x 18" facing in machine. Crosshead slide (behind gears) pivots around crank axis for gap adjustment. Hex-head bolts in ends of slides control doctor setting. Gears which drive backup rolls are hidden.



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Figure 53

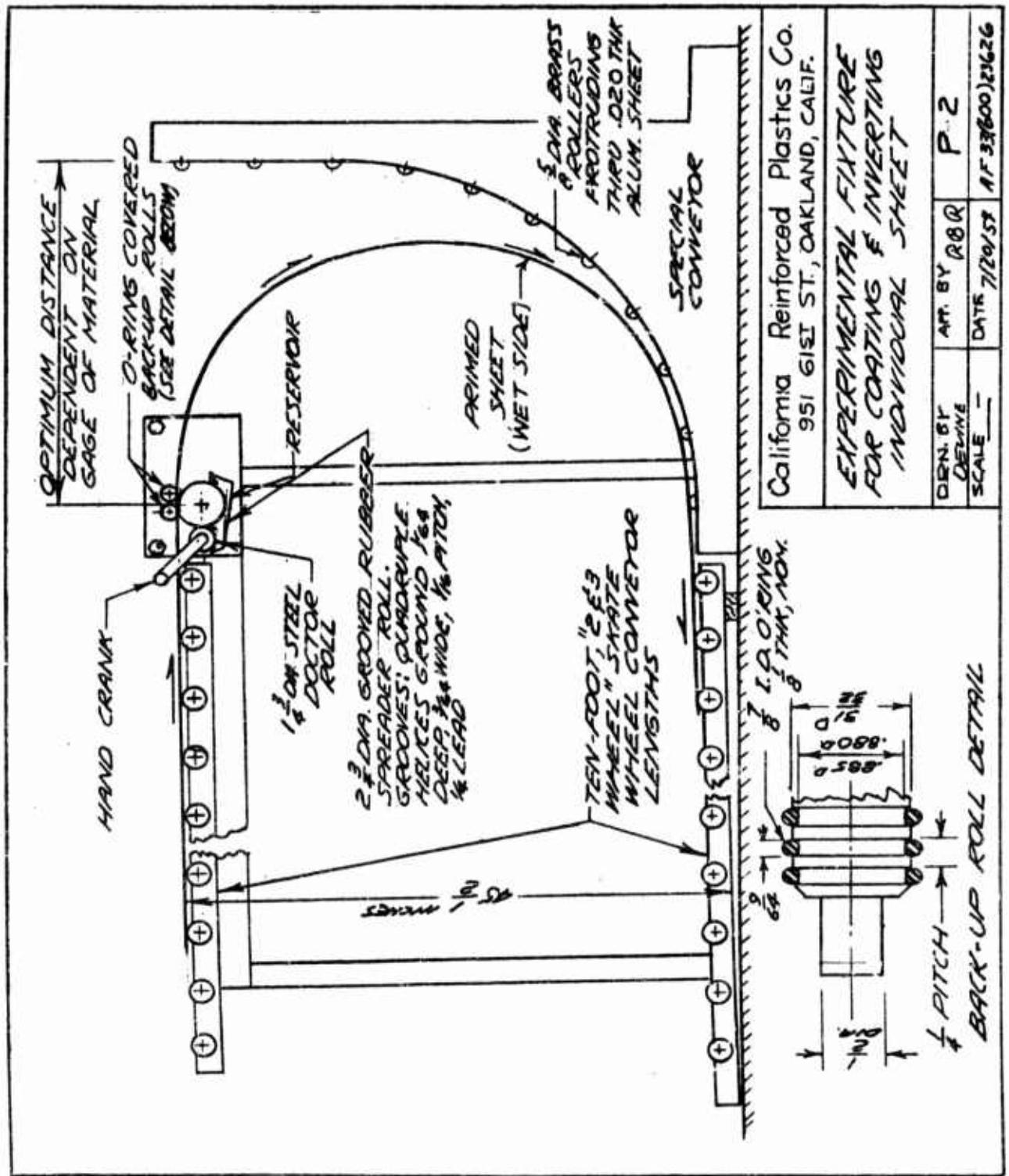


Figure 9

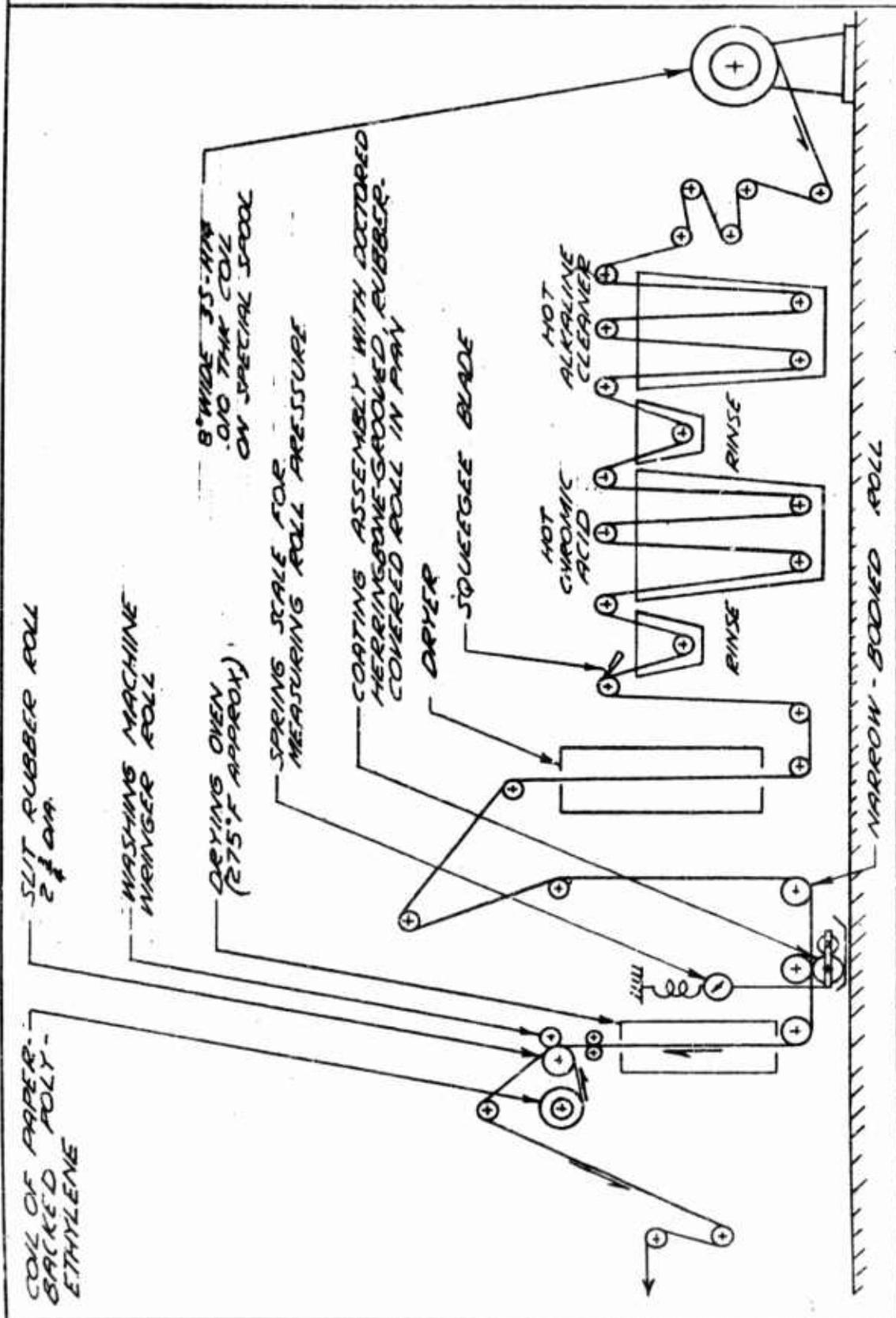


Figure 55 : Schematic of continuous priming and interleaving experiment conducted in foil-processing line. Material processed was 38-H4 coil, 0.010 inches thick and 8 inches wide. Adhesive was heavily dyed "PA-47", diluted in an equal part of thinner. Grooved-roll coater proved unsatisfactory in this run, and the paper-backed polyethylene became delaminated from the primed surface after passing over the first roll. The tracking of the web and the operation of the cleaning process were satisfactory.

FIGURE 56

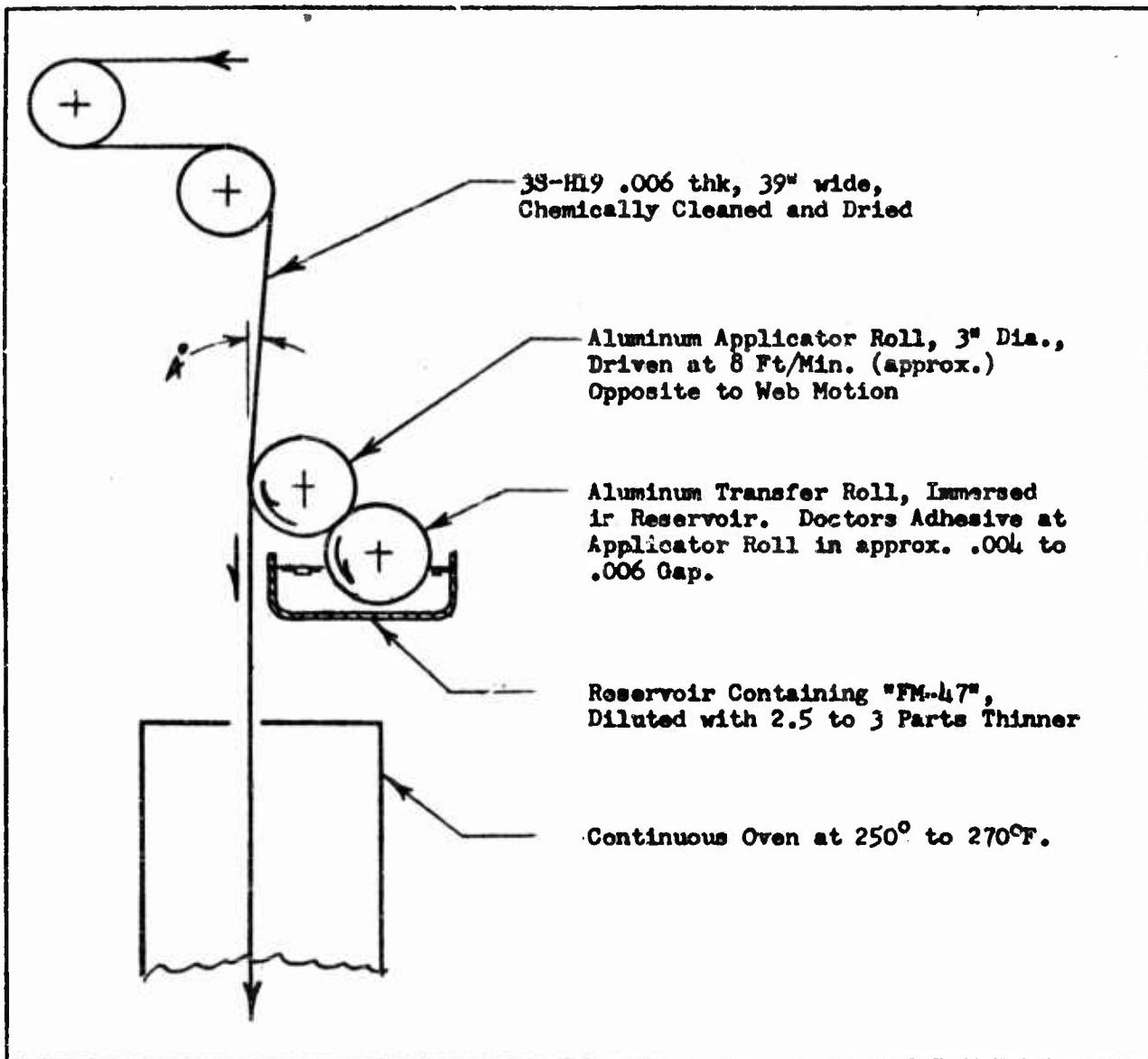


Figure 56: Schematic of reverse-roll coating system, used to apply a dilute "FM-47" prime coat to one side of 39 inch continuous strip of 3S-Hl9 foil, 0.006 inch thick. Although coating was smooth, uniform, and did not extend around the edges of the strip, the applicator roll tended to dry up under continuous use. This condition could have been minimized by enclosing the roll assemblies in a hood, and could have been eliminated by immersing the applicator roll in the reservoir. (The latter modification could not have been carried out with the strip passing downward, as shown here.)

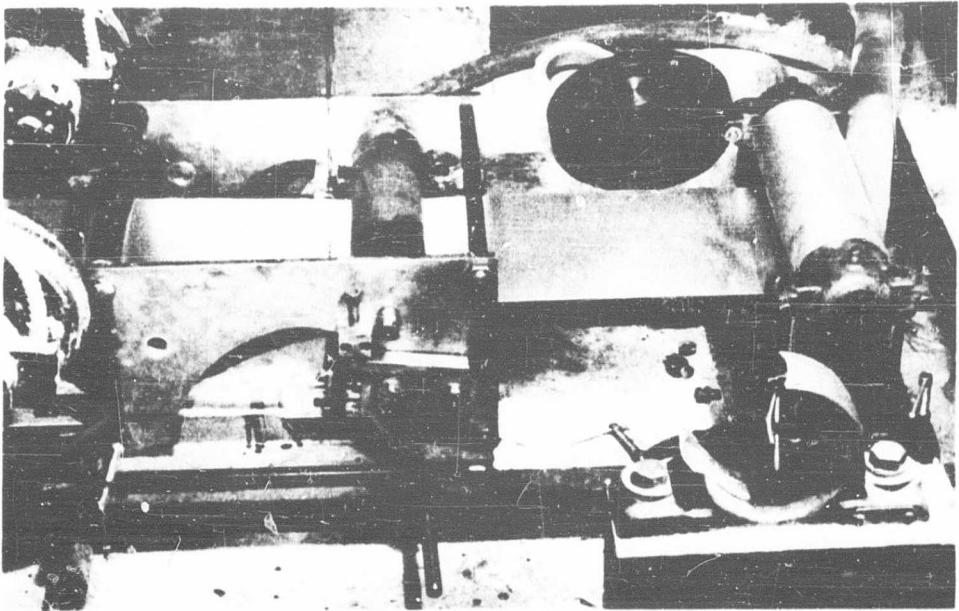


Figure 57: Grooved-roll coater, as set up in continuous priming and interleaving experiment conducted in production foil processing line. Web enters oven at left. Roll at right is "narrow-bodied".

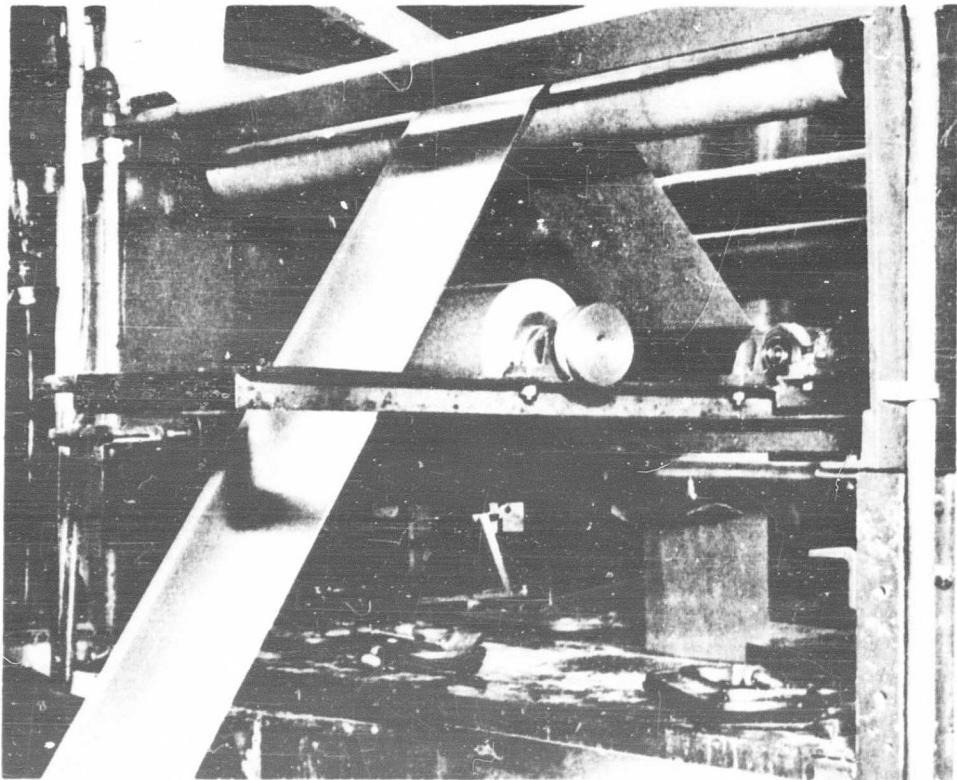


Figure 58: Experimental device for laminating paper-backed polyethylene interleaf to hot, primed, aluminum strip, as set up in production foil-processing line. Web emerges from oven at lower right. (Note delamination near upper roll)

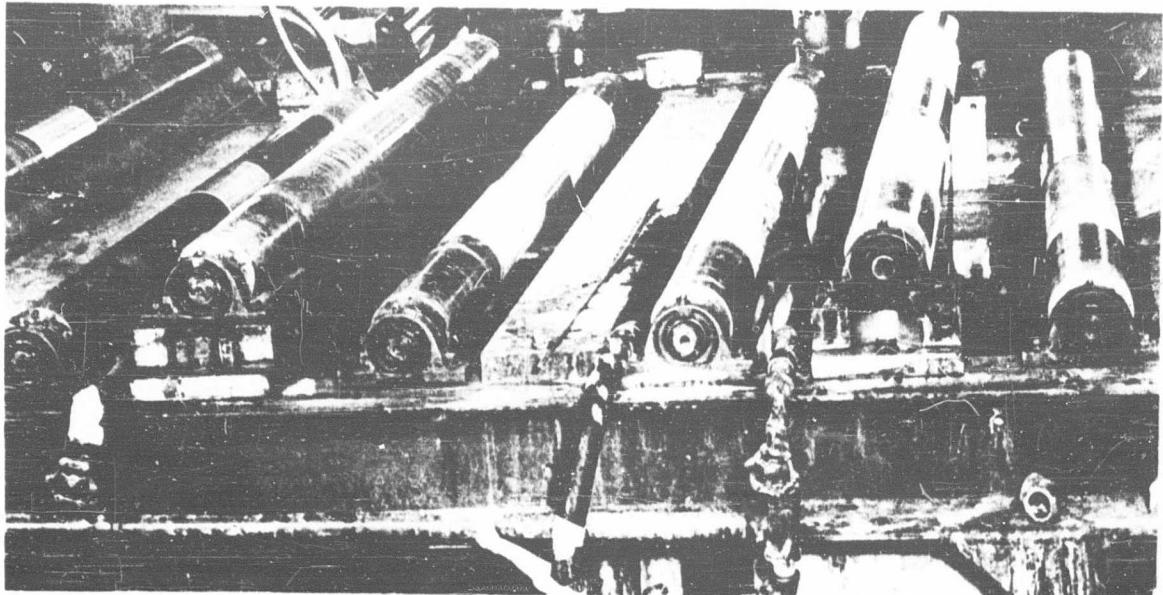


Figure 59: Strip aluminum (3S-H-14, 8" wide, 0.010 " thick) passing through production foil cleaning and rinsing stages at contractor's plant during priming and interleaving experiment.

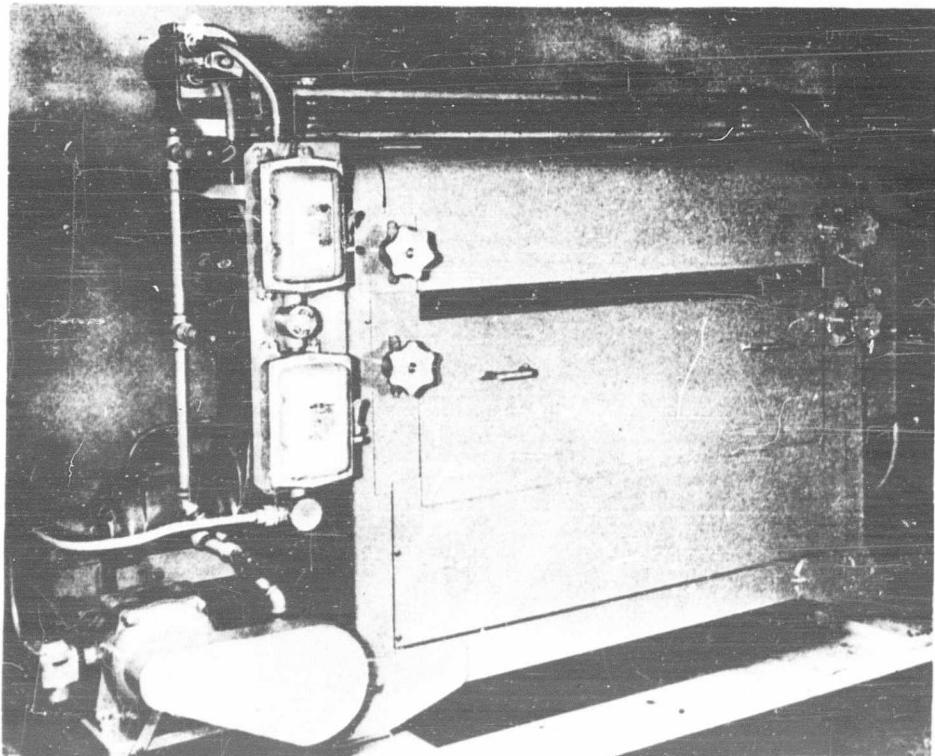


Figure 60: Enclosed roller coater with variable speed drive and glue circulating pump. (Photo courtesy Black Brothers Co.)

## SECTION II, Continued

### C - STUDIES OF CORROSION-RESISTANT MATERIALS FOR CLEANING TANKS AND RACKS:

According to survey information gathered early in the project, the use of the hot sulfuric acid-sodium dichromate solution in the preparation of facings for adhesion has resulted in a number of tank failures. Although dichromate is known to be a corrosion inhibitor, the contractor has no knowledge of a tank made of ferrous materials which has withstood continuous service. Tanks lined with plastic materials have shown similar histories of failure, probably because of the high temperature in combination with the oxidizing power of the dichromate. Lead-lined tanks have given reasonably good service as far as is known, and no failures of tanks made with ceramic materials have been reported.

Early in the project, the contractor evaluated a number of metals in an accelerated corrosion test. The results are shown in Table 29 and in Figures 61 through 65, at the end of this discussion. Tests were conducted in 150-cc beakers in a controlled-temperature bath set at  $196 \pm 2^{\circ}\text{F}$ . The test solutions -- one part sodium dichromate, ten parts sulfuric acid, and thirty parts water; and 25% sulfuric acid alone -- were replenished daily. The specimens were coupons, 1-1/2 inches wide, 3 inches long, and approximately 1/16 inch thick. Welds were made down the centerlines of some of the coupons with recommended rod materials. The total time of the test was 752 hours, but some of the materials were withdrawn sooner, after pronounced attack was in evidence.

All of the stainless steels showed significant deteriorations in the dichromate solution. The deterioration of the stainless in the sulfuric acid alone was very severe, except in the case of "CARPENTER'S STAINLESS NO 20 Cb". Apparently sodium dichromate accelerates corrosion rather than inhibiting it, in the case of "NO. 20" and "MONEL". (There is a case on record of a "MONEL" tank built to contain the acid-dichromate cleaning solution, which failed within 24 hours after being filled.)

Lead showed little attack in the plain acid, but built up a thick powdery scale in the cleaning solution. This scale was found to be loosely attached to the metal and the coupon was considered to have failed. (Note: the presence of lead is known to cause "smutting" on the surfaces of aluminum parts treated in room-temperature spot-welding etches. It is not known whether it does this in the solution in question.) The lining of tanks with lead is understood to be becoming obsolete, partly because of its tendency to creep and sag away from the structural tank walls.

The temperature chosen for these tests was unfavorable in that it was in excess of the recommended operating temperatures; however, it was far below the temperatures encountered where gas-firing might be used as a heating method. In general it appeared that none of the metals was suitable.

As a check on the above results, the history of the small tank used in the project for the cleaning of facings can be cited. This tank was built from "CARPENTER'S STAINLESS NO 20 Cb" sheet, before the coupon tests were performed. The material was known to be very costly, but was selected on the basis of its outstanding service with sulfuric acid. The tank was made to

II - C, Continued

hold ten gallons of sulfuric acid-sodium dichromate solution and was six inches wide, 24 inches long, and 18 inches deep. The walls were made from 14-gage sheet, welded (with "CARPENTERS NO. 20" welding rod) at the ends only. The sides and bottom were formed from the same piece. A lip was bent at the top and an angle-iron frame was tack-welded around the girth to prevent buckling. Four 500-watt electrical strip heaters supported the tank at the bottom. A thermostat well and a submerged air agitator were made from "CARPENTERS STAINLESS NO 20" pipe. The tank was in service from three to five days out of the week at 140° or 160°F, for approximately 15 months. Although considerable difficulty was encountered with electrical shorts in the heaters from acid dragout, the bottom welds (at the ends only; not directly over the heaters) remained sound. At the end of a year, however, leaks developed at the tack welds, which held the angle-iron restraining frame in place. These leaks were plugged successfully with "CARPENTERS NO. 20" welding rod. Periodic analyses of the test solutions indicated that significant quantities of ferric ion were entering the solution, presumably from the tank walls. Although this tank gave reasonable service, over the life of the project, its resistance to leakage was considered poor and the material is not recommended.

The field of plastic linings was also explored. Literature on plasticized and unplasticized polyvinyl chloride was procured from a number of firms who manufactured or distributed it under various trade names. In general, the literature indicated that "PVCs" are highly resistant to acids and acid fumes at temperatures under 140° - 150°F. Chromic acid and other oxidizers are usually quoted as an exception, with lower recommended temperature limits. It is claimed, probably with justification, that some types of polyvinyl chlorides are superior to others in temperature resistance. The temperature limitations on polyvinyl chlorides in the presence of oxidizers appeared to rule them out as a tank-lining material for the solution in question, but the contractor performed one exploratory experiment. Coupons of plasticized and unplasticized polyvinyl chlorides and of sheet "TEFLON" were placed in beakers of cleaning solution, in the same manner as were the metal coupons, except that the temperature was set at 150°F. Both "PVC" samples tended to stain the solutions and their surfaces became tacky after several days' immersion. The "rigid" material displayed some swelling from contact with the solution. Since the samples were procured from two different manufacturers, it is not considered that a fair evaluation of "rigid" vs. "plasticized" materials was made. The "TEFLON" sample appeared to have been unaffected by the solution.

The evaluation confirmed the belief that polyvinyl chlorides would be unsuitable for direct contact with the acid cleaning solution. There was no indication, however, that they would be unsuitable in evacuation hoods over the tanks, where temperatures are lower, or as sealing liners in internally heated ceramic tanks, where the brickwork provides insulation between the lining and the hot solution.

The use of "TEFLON" as a lining material was not considered because of its expense and the lack of experience in its application. It appears to be ideal for use as a "trim" material or as a bearing material for roll journals.

II - C, Continued

Of the tank materials under consideration, ceramics were the only class of material which had not been evaluated. It was decided that survey information would be of more significance than laboratory work in evaluating these materials. An additional survey of existing installations indicated that no failures had been experienced in a number of ceramic tanks being used with the sodium dichromate-sulfuric acid solution. Discussions with a number of manufacturers and studies of sales literature indicated that acid-resistant bricks or tiles were entirely resistant to acids and oxidizers. There was some uncertainty as to the resistance to oxidation of one of the types of materials used to bind the bricks together, however. Although the majority of fillers and mortars are known to be entirely satisfactory, it could not be finally determined whether some of these materials might be susceptible to oxidation attack, and it is recommended that prospective buyers obtain firm guarantees from the fabricators. There was some disagreement among ceramic tank fabricators as to the best means of compensating for expansion in long tanks, optimum material for an outer lining, etc., but these variables were believed to represent differences in opinion in a competitive field, and were not explored by the contractor.

It was concluded that a ceramic construction would be optimum for a tank containing the solution in question. Of the other types of construction considered, only lead-lined steel vessels appeared to have adequate resistance to attack, and these were undesirable on the basis of the likelihood that they would introduce undesirable contaminants in the solution.

Both ceramic and lead-lined tanks require immersion heating of the solution. Where the heating must be done by electricity, "PYREX" or similarly protected immersion heaters are necessary. Heaters of this type were observed in one relatively small ceramic tank holding the solution in question, and their performance was claimed to be satisfactory. Steam appears to be a much cheaper medium, however, and its use is recommended. The contractor has tried to determine, from questioning those experienced in the field, whether there would be any objection to the direct introduction of steam through nozzles, in preference to indirect heating in exchangers, and has found none. There is some question as to whether pressed carbon or ferrous nozzles would be preferable. Most carbon nozzles contain binding materials which are susceptible to oxidation by the dichromate. Ferrous nozzles, on the other hand, would tend to introduce iron (a contaminant which is suspected of being harmful) into the solution. No conclusion could be made as to which of the two would be more suitable.

It became obvious, early in the project, that some investigation of various materials should be made for the racks used to transport the aluminum sheets through the solutions. The first racks used in this project in conjunction with the ten-gallon alkaline and acid cleaning tanks were of welded black iron, coated with cured layers of phenolic and epoxy adhesives. The early breakdown of the resins and attack of the metal indicated that these racks were inadequate. An experimental rack of "rigid" polyvinyl chloride, cut and hot-formed from thick plate, was procured from a local tank manufacturer. This material softened excessively in the hot ( $180^{\circ}\text{F}$ ) alkaline solution, and stained the sheet surfaces by its proximity in the ( $140^{\circ}\text{F}$ ) acid solution. It was not determined whether this brown stain affected adhesion.

II - C, Continued

The last and most successful rack tested was made from 2S aluminum round wire and bar, "HELIARC" welded. The high purity of this metal gave it a reasonable degree of resistance to acid attack. This rack was used throughout the major part of the project without evidence of failure, other than a blackening of the welds and the formation of a hard white crust on the surface. A weight check, performed after 65 cycles at tank temperatures of 140° and 160°F, revealed that the rack had lost only 1.8% of its total weight of 1.12 pounds. The wet surface area was approximately 175 square inches, and represented about 90% of the total area of the rack. This rack material is considered to have two basic advantages over other materials, in that it does not introduce harmful contaminants, and does not set up electromotive potentials at the sheets. The hard, abrasive surface produced by long use would undoubtedly be objectionable where large parts must be processed without scratching. It is recommended that large racks be made with "TEFLON" trim parts, utilized as bumpers and rollers. Small discs or bushings of this material should be placed in critical locations in the structure before it is welded together.

Corrosion-resistant materials are not usually required for containing alkaline cleaning solutions. Black iron tanks, indirectly fired with gas, are generally satisfactory. The electrically heated, black-iron alkaline tank used in this project became heavily rusted above the level of the solution, apparently from condensation. The submerged portion remained completely unaffected, however.

This concludes the discussion of investigations of various corrosion-resistant materials conducted in this project. A summary discussion of recommended materials for immersion in the sulfuric acid-sodium dichromate solution is also contained in "Specification S-4" (continuous-coil processing line) which is included in Appendix IV of this report.

TABLE 29  
RESULTS OF ELEVATED-TEMPERATURE CORROSION TESTS  
ON METALLIC TANK MATERIALS  
Temperature: 196°F

Solution	Material	Weld	Wt. Loss Pet.	Thickness Loss Mils.	Time Immersed Hours	Remarks
1:10:30, Sodium Chromate, Sulfuric Acid, Water	"CARPENTERS STAINLESS NO. 20 Cb" *	Same	11.2	6.9	752	Porosity, & undercutting in weld
	T-316*	Same	25.5	19.8	752	No apparent local attack at weld
	T-304 (as rolled)	T-308	28.7	19.6	752	Cracks above solution, pierc- ing specimen
	T-430*	R 2520	12.6	6.0	330	Local pitting above solution, piercing specimen
	"MONEL"	Same	3.6	2.0	2	Effervesced
	Black Iron	Same	26.6	20.2	2	Effervesced
25% Sulfuric Acid	Lead*	None	1.67 (Scale Removed)	---	752	Thick, powdery, yellow scale
	"CARPENTERS STAINLESS NO. 20 Cb" *	Same	0.27	0.1	752	Apparently unaffected
	T-316	Same	3.5	2.2	2	Effervesced
	T-304 (as rolled)	T-308	12.0	4.9	2	Effervesced
	T-430	R 2520	46.3	34.6	2	Effervesced
	"MONEL"	Same	20.0	7.6	213	Unsubmerged portion attacked
	Lead	None	0.018	---	752	Thin, gray flaky scale

\* See photographs (Figs. 61 - 65)

CORROSION TEST SAMPLES

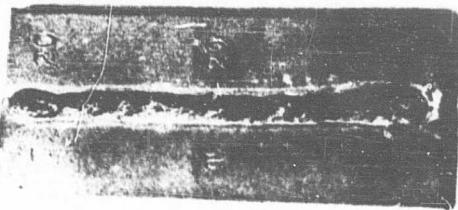


Figure 61: "CARPENTERS STAINLESS NO. 20 Cb" in 25% Sulfuric Acid.  
(No evidence of local attack.)

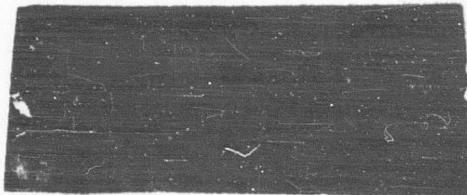


Figure 62: "CARPENTERS STAINLESS NO. 20 Cb" in Sulfuric-Dichromate cleaner. Note weld porosity, undercutting at lower right end of weld, and attack at edge of heat-affected area.



Figure 63: Stainless 316 in cleaner.  
(No local attack in evidence.)



Figure 64: Stainless 430 welded with 2520, in cleaner. Pitted area near weld at left pierces specimen.

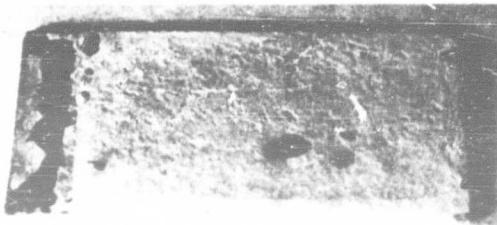


Figure 65: Lead in cleaner. Note heavy scale deposit.

## SECTION II, Continued

### D - CONTINUOUS CLEANING AND PRIMING OF FACINGS

#### Investigation of Feasibility

The survey of existing methods, conducted at the start of the project, did not reveal any instances where highly advanced production techniques had been applied to the preparation of aluminum facing sheets for sandwich bonding. All facing materials were purchased in the form of flat, cut sheets, and were processed by batch methods. An exception to this general rule was observed at one plant, where the cleaned facings were passed through a spray booth on a continuously moving paper-covered conveyor, and then carried through a continuous drying oven. The cleaning in this case was performed by conventional batch methods.

Since sandwich processing was divided over a relatively large number of firms, the square footage requirements of most of the firms were not usually so large as to tax the capacities of the batch-processing facilities in producing finished facings. The operations involved in cleaning, acid treating, and priming the facings were usually considered to be as critical as other processes involved in the manufacture of the finished sandwich. The large number of operator-controlled variables usually made it necessary to maintain close quality control on the parts. One of the principal drawbacks to batch processing appeared to be the necessity for careful handling to avoid contamination of the cleaned surfaces. Most manufacturers primed the parts within a few hours after cleaning, a requirement which called for close integration between the cleaning and priming departments. High humidity conditions were reported to have an adverse effect on the primed surfaces, particularly where the parts were sprayed.

It was obvious that many of the problems associated with the cleaning and priming of facing material could be minimized or eliminated by the application of automatic processing techniques. Continuous, mechanized processing of facings in the form of cut sheets was first considered. It was known that individual steel sheets had been processed in fully mechanized systems, in preparing for drawing and stamping operations in the automotive and appliance industries. The processing here consisted of cleaning and priming, but "cleaning" in this case represented only an alkaline or vapor degreasing operation, and "priming" was usually merely an application of a soap-like drawing compound to both sides of the sheets. The sheets traveled through these lines horizontally, on conveyors.

II - D, Continued

The automatic processing of individual sheets horizontally did not appear to be practical in the case of aircraft aluminum alloys for the following reasons:

- (1) It would be difficult to maintain scratch-free surfaces, and to prevent damage to thin-gage sheets.
- (2) It would be difficult to design mechanized equipment with sufficient corrosion resistance to transport the sheets through a dip or spray of the hot acid solution which is required in preparing aluminum sheets for adhesion.
- (3) There is no known practical means of applying adhesive primes automatically to one surface only of individual thin-gage sheets.

Designers and suppliers of continuous processing equipment were generally negative in their comments on the feasibility of processing thin-gage aluminum sheets horizontally.

It appeared to be generally feasible to apply mechanization to individual stages of the conventional rack-type processes to bring about higher production capacities and lowered costs. These modifications would take the following form:

- (1) Replacement of existing monorail hoist systems with continuous or circular monorails from which two or more racks of parts could be kept in the cleaning process at the same time. The movement of these racks would be controlled in the same manner as at present. Automatic time-cycle hoist controls would have doubtful feasibility because of the wide range of process times in the various stages of the cleaning cycle.
- (2) Use of a continuously moving conveying system for transporting the parts through a spray booth and tunnel-oven.

A proposed layout of a semiautomatic batch system is shown schematically in Drawing PL-2 in Appendix III of this report. Estimated cost data for a line of this type are shown at the end of this discussion.

This degree of mechanization would bring about a substantial increase in production capacity, and would undoubtedly tend to lower unit costs. This type of process line would not entirely relieve the existing production problems, however. Handling of the parts would still be required at the end of the cleaning cycle. As many as ten workmen might be required to perform all of the loading, unloading, hoisting, and spraying operations in a line running at full capacity. (Eight workmen have been assumed in the cost estimate.) There would still be some dependence on the judgment and skill of the workmen in producing consistently satisfactory parts.

II - D, Continued

It became evident early in the project that the most economical and reliable means of processing facing materials would be in a continuous "coil" or "strip" line. Although the contractor was familiar with the processing of "foil" gages (under 0.008 inches in thickness), there was very little available information on the continuous processing of coils in the "sheet" gages. Although aircraft firms occasionally heat-treated alloys in the coil form the material was not subsequently processed in this form. It appeared that the following factors relating to the feasibility of processing in the coil form required investigation:

- (1) Availability and cost of coiled, heat-treated aluminum alloys.
- (2) Degree of advancement of coil-processing technology.
- (3) Availability of suitable equipment.
- (4) Strip thickness limitations.
- (5) Feasibility of incorporating highly corrosive chemical treatments in the process.
- (6) Feasibility of continuously applying adhesive primers.
- (7) Operational and equipment costs of coil lines.

An extensive survey was begun in an effort to make contacts with firms or individuals who were experienced in the design and operation of the type of equipment in question. It was anticipated at this time that those who were familiar with continuous processing techniques would probably not have a working knowledge of the particular materials and processes involved in preparing aluminum for adhesive bonding. Evaluations of a number of process variables were initiated in order to be able to fully define the requirements of a continuous strip process. These evaluations included studies of the effects of temperature, concentration, and solution age on optimum acid treatment time (Section I, Part F), evaluation of methods for applying adhesive primers to metal sheets (Section II, Part B), and studies of corrosion-resistant materials (Section II, Part C).

The preliminary survey of equipment manufacturers revealed that the manufacturers of the following four general classifications of equipment might be qualified to supply all, or a portion of, a continuous-coil processing line which would prepare aluminum for adhesive bonding.

1. Rolling, pickling, slitting and heat-treating equipment.
2. Foil-converting equipment.

II - D, Continued

3. Textile equipment for continuous handling of cloth.

4. Precoating equipment for applying enamel to coiled sheet, for use in awnings, venetian blinds, etc.

The manufacturers in the first group indicated a general interest and were able to make constructive suggestions on the proper configuration for the line. The equipment they proposed to supply was of a generally rugged construction, and represented an adaptation of equipment used in high-speed, high-tension equipment found in steel mills.

The manufacturers of both foil-converting and textile-processing equipment indicated that they would be interested in undertaking the construction of such a line, but that special laboratory and development efforts would be required to prepare a practical design.

The manufacturers of equipment for precoating coils supply a relatively new type of industry which is undergoing rapid growth. The materials processed here are usually non-heat-treated coiled aluminum in a 1/2-hard or 3/4-hard condition and in thicknesses ranging from 0.020 inches to 0.060 inches. These materials are passed at speeds of the order of 50 feet per minute through sprays of alkaline cleaner, acid solution, and rinse water, and are continuously coated with enamels in various colors. The coatings are baked in the same continuous operation, in long "tunnel ovens", after which the webs are rewound and stored until slitting, shearing, forming, and assembling operations are performed. From two to three operators are required. The operation of these lines is usually sustained without stopping for periods ranging from five days to two weeks. As one coil is completed, a new coil is spliced in place by means of a wire-stitching machine. The width capacities of the earlier precoating lines was very limited, but some lines presently under construction are designed to handle 20-inch and 36-inch material, and it is anticipated that 48-inch lines will be built in the near future. The tensions, roll diameters, power requirements and over-all cost of these lines are relatively low when compared with steel strip lines because of the lightness and flexibility (low modulus) of the material, and the lack of slitting, forming and rolling operations in the process. It is estimated that from 12 to 15 of these lines are in operation, the majority of which process material under 12 inches in width.

It is significant to note that the type of chemical-treating, coating, and curing operations performed in these lines are analogous to those performed on aluminum sheet prior to adhesive bonding, and that they are performed in the same consecutive order. It was decided that this type of equipment should receive the most thorough coverage in continued survey and contact work in connection with adhesive bonding.

II - D, Continued

At this point, a preliminary schematic drawing, showing a basic proposed layout of the components, was sent to the manufacturers of all the types of equipment covered in the survey. The project engineer then visited seven Eastern and Midwestern firms who appeared to be able to contribute information. Significant amounts of information were exchanged by telephone with nine other firms, during the trip. Correspondence was exchanged with approximately 50 additional firms, in the course of contact and survey work relating to the development of a coil line, and a number of additional local contacts were made by personal visit or telephone.

The majority of the firms visited were equipment manufacturers. The sales offices and laboratories of the Aluminum Company of America were visited in Pittsburgh, Pa. The continuous-strip pickling and annealing facilities were observed in operation at U. S. Steel's "Sheet and Tin" plant in Gary, Indiana. A typical precoating line for applying enamel to continuous webs of aluminum was observed at the firm of Roll Coater, Inc., in Pendleton, Indiana. Several of the photographs at the end of this discussion show the Roll Coater line in operation. The builders of this line, the Gasway Corporation, were visited in Chicago.

The information collected in this trip, and in response to the distribution of the preliminary drawing, indicated that it was entirely feasible to construct a continuous-coil line for cleaning and priming wide heat-treated aluminum strip in the coil form, for use as facings in sandwich assemblies. The manufacturers were interested in learning more about the details of the process and indicated that they would supply practical comments and details which could be used in preparing specifications and drawings.

It appeared that the roll layout, oven, spray washer, rinses, and moving parts of the line could be patterned after existing precoating lines. The acid treatment would require a dipping process rather than the conventional spray. The strip would be passed over stoneware rolls in a long shallow ceramic tank, in the same manner as steel strip is pickled. Some modification of the coating system would probably be required to enable it to handle high-viscosity adhesives with "low-boiling" solvents, and to be able to process the light gages used in sandwich assemblies.

It would be possible to combine the functions of a commercial precoating line and a line for processing heat-treated coils into the same unit. This would entail mounting the acid-solution spray chamber above the ceramic tank used for the sulfuric acid-sodium dichromate solution, and using them alternately. Conversion of the wider precoating lines to permit cleaning and adhesive priming of aircraft grades of aluminum would be desirable in the event of total mobilization. An additional function of such a line could be the application of nonelectrolytic, chemically applied, anodic coatings for military and commercial use.

Roll Diameters

There was some disagreement among equipment manufacturers as to the effects of material thickness, gage, and strength in determining what roll diameters should be specified. Most manufacturers who worked with steel felt that a diameter of 12 inches would be much too small to carry aluminum strip 0.040-inch-thick. Those who were experienced in handling aluminum strip knew that 0.051-inch-thick metal of relatively low yield strength could be passed over 12-inch rolls, but felt that heat-treated material would be too "stiff". A formula for predicting the stress in the outer fibers is quoted as follows:

$$\text{Stress} = \frac{\text{Elastic Modulus} \times \text{Strip Thickness}}{\text{Roll Diameter}}$$

This formula indicates that a stress of approximately 36,000 psi would be induced in aluminum and a stress of 100,000 psi would be induced in steel by passing 0.040-inch-thick strips of the two metals around a twelve-inch roll. Ordinary steels and non-heat-treated aluminums would be cold-worked under these conditions, but heat-treated aluminums would not. The soft outer material on clad aluminums would be cold-worked by deflections of this order but the structural properties of the sheet as a whole would be substantially unaffected.

The stress formula in itself does not indicate whether an excessive tension might be required to wrap the strip snugly about the roll. Experiments have indicated that a tension of 2.8 lbs. per inch of width is required to cause 0.040-inch-thick alclad 75S-T6 to wrap 180 degrees about a 12-inch-diameter drum, with full contact at the apex of the bend. This would require a total tension of approximately 100 lbs. on a 48-inch wide strip, whereas approximately 350 lbs. would probably be required to prevent excessive sag in the oven catenary, in such a system. Twelve inches represents a standard roll diameter on a line of this type and appears to be adequate for heat-treated aluminum in thicknesses up to 0.040 inch.

Availability of Coiled, Heat-Treated Aluminum

An analysis of the availability of coiled, heat-treated aluminum on the basis of discussions with the three major suppliers, was made at this time. Until very recently, heat-treated aluminum had not been available in the coil form in widths greater than 12 inches in thicknesses under 0.016 inches, and 24 inches in thicker gages. One aluminum company has recently made available heat-treated coiled sheet, 36 inches wide, in thicknesses of 0.025 inches and greater. Since the most common thickness used in sandwich panels is 0.016 inches, and since a major portion of the work calls for widths in excess of 24 inches, the present availability of coil would not justify the purchase of a continuous processing line. Another aluminum company has advised the contractor that their future plans call for the installation of continuous heat-treating equipment which will enable them to furnish 48-inch-wide heat-treated, coiled material in practically all of the gages. Although no definite date for the start of operation of this unit can be set, it is estimated that from two to four years will be required. Although it is not definitely known, it is probable that all three of the major aluminum suppliers have plans for extending the width ranges of their coiled, heat-treated aluminum products.

II - D, Continued

It should be noted that there is a distinct advantage in purchasing the material in the coil form, regardless of whether the material is processed in this form or not. The approximate savings in cost per pound and per square foot of 24S-T aluminum in various gages, which can be realized in this manner are tabulated as follows:

<u>THICKNESS</u>	<u>SAVINGS</u>		
	<u>Inches</u>	<u>Cents per Pound</u>	<u>Cents per Square Foot</u>
.012		13.7	2.3
.016		11.3	2.6
.025		7.3	2.6
.040		2.9	1.6

The cost savings per square foot of finished sandwich would be twice those per square foot of sheet, or 5.2 cents per square foot, where 0.016- or 0.025-inch facings are used. An additional saving brought about by buying in coil is the saving in scrap waste, resulting from efficient shearing.

In the survey of manufacturers, particular attention was given to "shearing and stacking" lines. Photographs of two of these lines are shown in Figures 70 and 71. A unit of this type shears coils at speeds of the order of 150 FPM into lengths from one to twelve feet long, within a tolerance of approximately 1/32 inches. The cost of these units runs from \$15,000.00 to \$25,000.00. They have gained increasing acceptance in the automotive industry, where there has been a trend toward purchasing sheet steel in the coil form.

It should be noted here that the quality of most existing heat-treated coiled sheet (with the exception of the newer 36-inch-wide material) is below that of flat sheet, in that it is very likely to be warped, and inconsistent in hardness, from the effects of the batch heat-treating process. This condition is brought about by temperature gradients in the relatively large mass of the material during the heat-treating process and is the current limiting factor on coil width. Currently produced heat-treated flat sheet also shows some warpage originally, but is "stretcher-leveled" to improve its flatness. This leveling process brings about a small upgrading of physical properties which allows the temper designation to be changed from "T-4" to "T-3". The change is of the order of only 2000 psi and is not a major consideration in choosing between coil and sheet. Coils which are heat-treated in a continuous-strip process will show less warpage than do current batch-processed coils, as far as is known.

Tracking

The problem of keeping wide, moving strips accurately centered has until recently been a retarding factor in the development of continuous-coil processing systems. Coiled materials usually contain rolling or heat-treating irregularities which cause them to

weave or track sideways when they are passed over a number of plain cylindrical rolls. The problems increase as the width of the material and/or the lineal speed are increased. Although there are a number of well-established methods for keeping strips of paper, cloth, and other low-modulus materials properly centered, these methods are not generally applicable to metal strips. The current upward trend in width toward 36 inches and 48 inches has largely been made possible by the advent of the "LORIG-ALIGNER" system, patented by U. S. Steel. This system involves the use of metal and rubber-covered rolls of special construction, which apply centering forces to the moving strip. The strip-processing industry currently gives this system almost universal acceptance as a principal means of improving tracking. Individual equipment manufacturers often augment it with systems of their own design.

The inventor of this system, Mr. E. T. Lorig (Chief Development Engineer, Engineering Division, U. S. Steel Corp.), was consulted in Pittsburgh during the eastern tour, and rendered further consultation during a visit to the contractor's facility.

The tracking problems in the system in question will be minimized by the relatively low speeds, but will undoubtedly require special attention because of the warpages inherent in heat-treated materials.

#### Preparation of Proposed Equipment Specifications

Since the application of coil-processing techniques to the preparation of facings appeared sound, and since there was a likelihood of obtaining coiled aluminum within a few years, effort was directed toward drafting a practical design layout for such a unit, and determining the costs of its operation.

A proposed specification, "S-2", and a second schematic drawing, "L-3", were distributed among the firms who had been previously consulted, with the request that they submit technical comment and criticism. (This version of the specification and drawing were omitted from the report since they present some obsolete information, and may be confused with the newer drafts which are more accurate and complete.)

The comments and criticisms received from these inquiries, and the more detailed process data obtained from experimental studies, were combined into a Proposed Specification "S-4" (not a Government specification), which appears with drawings "L-4", "L-5", and "L-6" in Appendix IV of this report. This material was sent out to the equipment manufacturers with the request that they retain it for future reference, after submitting some rough cost estimates and additional final comments on practicability. Since some of these final criticisms were of a very pernicious and basic nature, it was felt necessary to issue a supplement to the original specification. This supplement appears in Appendix IV, along with the original specification. (The specification itself has received minor corrections in form and accuracy since being distributed.) The intent in preparing this specification material was not to set forth rigid or binding limitations, but to provide a useful guide to prospective suppliers in understanding the process requirements, and to give a prospective buyer a sound basis for auditing and evaluating future proposals.

II - D, Continued

Sources

The following is a listing of manufacturers who contributed technical information in the surveys, and/or appeared to be capable of providing the major portion of the equipment for the proposed continuous-coil cleaning and priming line, and for the shearing and stacking line. The firms are arranged alphabetically in groups corresponding to the general type of equipment that they supply. (This list does not constitute an endorsement of the qualifications of these firms, and undoubtedly overlooks some firms who are qualified to supply this equipment.)

(1) Continuous-Coil Processing Equipment, general:

Frank W. Egan & Co. Bound Brook, New Jersey	James Hunter Machine Co. North Adams, Massachusetts
Gasway Corporation 6463 No. Ravenswood Ave. Chicago 26, Illinois	Ovens for Industry, Inc. 2032 W. 105th Street Cleveland, Ohio
	Wean Equipment Corp. 22800 Lakeland Blvd. Cleveland 17, Ohio

(2) Acid-Resistant Tanks:

Maurice A. Knight Kelly Avenue Akron, Ohio	Nukem Products Corp. 600 16th Street Oakland 12, California
	Stiehle & Co. 605 Addison Street Berkeley 10, California

(3) Ovens:

Aladdin Heating Corp. 111 West Avenue., 137th San Leandro, California	Grieve-Hendry Co., Inc. 1811 West Lake Street Chicago 12, Illinois
Drying Systems, Inc. 1808 W. Foster Avenue Chicago, Illinois	W. C. Matheson Co. 228 - 9th Street San Francisco, California
	J. O. Ross Engineering Corp. 600 St. Paul Avenue Los Angeles, California

II - D, Continued

(4) Coaters:

The Black Bros. Equip. Co.  
Mendota, Illinois

Union Tool Corp.  
Warsaw, Indiana

Potdevin Machine Co.  
200 North Street  
Teterboro, New Jersey

John Waldron Corp.  
P. O. Box 791  
New Brunswick, New Jersey

(5) Spray Washers:

Cincinnati Cleaning  
& Finishing Machinery Co.  
Hageman Street  
Sharonville, Ohio

George Koch and Co.  
Evansville, 4 Illinois

Drying Systems, Inc.  
1808 W. Foster Avenue  
Chicago, Illinois

L. W. Lefort  
2335-52nd Street  
Vernon, California

Hanson-VanWinkle-Munning Co.  
Matawan, New Jersey

Magnus Chemical Co.  
Garwood, New Jersey

James Hunter Machine Co.  
North Adams, Massachusetts

Peters - Dalton  
17900 Ryan Road  
Detroit 12, Michigan

Industrial Systems Co.  
28 Main Street  
Matawan, New Jersey

N. Ransohoff, Inc.  
N. 5th St. at Ford Blvd.  
Hamilton, Ohio

(6) Special Rolls:

Mount Hope Machinery Co.  
15 Fifth Street  
Taunton, Massachusetts

United States Steel Corp.  
Pittsburgh, Pa.

(7) Shearing and Stacking Lines:

Dahlstrom Machine Works, Inc.  
4227 W. Belmont Avenue  
Chicago 41, Illinois

Union Tool Corp.  
Warsaw, Indiana

The rough equipment cost estimates received from the prospective suppliers showed extremely wide variations. Some of the suppliers evidently interpreted the line as being almost entirely a special design which would require initial research and development work, while others regarded it as more or less standard. It appeared to be generally desirable to place the responsibility for fabricating the line in the hands of one firm if possible.

A continuous-coil processing line (without the shear line) could be purchased for a price of the order of \$150,000 to \$175,000.

In order to determine whether the cost of the line is justified, the square-footage costs, with continuous-coil processing techniques and with existing batch techniques, are estimated here. A third case that will be considered is a continuous monorail system for handling cut sheet. (See Plant Layouts, Appendix III.) These costs are computed on the basis of facing square-footage, and must be doubled for sandwich cost estimates. It is important to note that the estimates assume that optimum process conditions as determined in this project, are upheld in all three cases.

Square-footage costs shown here for batch operations are highly theoretical, and are not based on actual data collected in the industry. Actual costs of this type are generally unavailable from sandwich manufacturers. Utilization rates vary considerably from firm to firm, whereas these costs assume only one utilization rate, presumed to be at a comparatively high level.

a) Assumptions:

- (1.) The following three types of production systems are assumed:

Case X:

Low-production batch process; single monorail, one rack every 55 minutes, containing 6 sheets, 4' x 8'; priming done by one spray operator; sheets dried in batch oven. Total crew: 3 men.  
Initial cost of system: \$50,000.00  
Total output per shift: 1500 square feet

Case Y:

High-production batch process; continuous monorail, one rack every 15 minutes, containing 6 sheets 4' x 8', priming done by two spray operators as sheets travel by on moving conveyor; continuous oven used for drying.

Total crew: 8 men  
Initial cost of system: \$75,000.00  
Total output per shift: 5,000 square feet

Case Z:

Continuous-coil cleaning and priming line; with

II - D, Continued

supplementary coil-shearing line. Speed varies with gage. Average width of material is 36 inches (max.: 48 inches). Priming done by roller coater.

Total crew: 4 men  
 Initial cost of system: \$175,000.00  
 Total output per shift: 10,000 to 25,000 square feet  
 as tabulated below:

Thickness Inches	Machine Speed (approx.)	<u>Sq. Ft.</u> <u>Hour</u>	<u>Sq. Ft.</u> <u>Shift</u>	<u>Sq. Ft. per year</u>	
				<u>50 weeks</u>	
				(a)	(b)
.012	18 FPM	3200	25,000	6,250,000	18,000,000
.016	12 "	2100	16,000	4,000,000	12,000,000
.025	10 "	1800	14,000	3,500,000	10,500,000
.040	7 "	1250	10,000	2,500,000	7,500,000

(2.) For purposes of these estimates, it is assumed that these systems are used either (a) 5 shifts per week or (b) 15 shifts per week. The burden rates corresponding to these shift utilizations are (a) 2.0 x Direct Labor and (b) 1.5 x Direct Labor.

(3.) Direct labor in every case is assumed to cost \$2.25 per man hour.

(4.) The total square footage rates have been adjusted downward from the theoretical maximum in every case to allow for down time, relief periods, etc.

b) Base Costs Proportional to Square Footage in All Methods:

It will temporarily be assumed in this estimate that the cost of aluminum raw materials in the three systems is the same, and this cost will not be included in the cost of processing. (As noted in the discussion of the availability of coiled, heat-treated aluminum, the price of coil stock is 1.6¢ to 2.6¢/sq.ft. less than the price of cut sheet.)

(1.) Adhesive: Assumes dilute (1:1) "FM-47" (or equivalently priced adhesive) applied to give 0.002 lbs./sq. ft. solids.

Assumed Prices: "FM-47" = \$4.50/gal.; Thinner = \$2.75/gal.  
 Weight of liquids: 8 lb./gal.  
 Solids content of adhesive = 20 percent.  
 Cost = (.002) x (\$4.50 + \$2.75)  
 (.2) (8)  
 = \$.009/sq. ft. = 0.9¢/sq. ft.

(2.) Chemicals: Assumes that acid must be replaced after 60 sq. ft./gal. (200,000 sq. ft. per tank) have been processed:

Acid:	0.4¢/sq. ft. (see Discussion 6, Section I,
Alkaline (assumed):	0.1¢/sq. ft. Part F)
Total	0.5¢/sq. ft.

II - D, Continued

c) Costs Proportional to Number of Shifts:

(1) Labor: (at \$2.25/man-hour = \$18.00/man-shift)

X: 3 men x \$18.00 + 1500 sq. ft. = \$.036/sq.ft. = 3.6¢/sq.ft.  
 Y: 8 " " " + 5000 sq. ft. = \$.029/sq.ft. = 2.9¢/sq.ft.  
 Z: 4 " " " + figures tabulated below

Thickness Inches	Sq. Ft. Shift	Labor Cost, Case Z \$/Sq.Ft.      ¢/Sq.Ft.	
.012	25,000	.0029	0.3
.016	16,000	.0045	0.45
.025	14,000	.0051	0.5
.040	10,000	.0072	0.7

(2) Utilities:

Gas: Assume total gas load in all systems is  
 3 million BTU/hr = 3 x (1360 cu. ft./million BTU)  
 = 4000 cu.ft./hr.

Assumed cost: 30¢/thousand cu. ft.  
 Total gas cost per shift: \$9.60

Electricity: Assume \$1.00/shift

Water: Assume consumption = 10 GPM @ 0.025¢/gal. = \$1.20/shift  
 Total utility cost/shift: = \$11.80

Utility square-footage costs:

X: \$11.80 + 1500 = \$.008/sq.ft. = .8¢/sq. ft.  
 Y: " + 5000 = \$.002/sq.ft. = .2¢/sq. ft.  
 Z: " + figures tabulated below:

Thickness Inches	Sq. Ft. Shift	Utilities Cost, Case Z \$/Sq.Ft.      ¢/Sq.Ft.	
.012	25,000	0.0005	0.05
.016	16,000	0.0007	0.07
.025	14,000	0.0008	0.08
.040	10,000	0.0012	0.1

II - D, Continued

d) Burden (not including amortization)

Case	Direct labor, \$/sq.ft.	Burden	
		a) 5 shifts/wk • 2.0 x D. L.	b) 15 shifts/wk • 1.5 x D. L.
X	3.6	7.2	5.4
Y	2.2	<u>4.4</u>	<u>3.3</u>
Z { .012	0.29	0.6	0.4
	.016	<u>0.9</u>	<u>0.7</u>
	.025	1.0	0.8
	.032	<u>1.4</u>	<u>1.1</u>

e) Machine Amortization:

Assume: 5-year economic life,  
10 pct. salvage value,  
Straight-line depreciation

Annual charges:

$$X: \frac{\$50,000 - \$5,000}{5 \text{ years}} = \$9,000/\text{yr.}$$

$$Y: \frac{\$75,000 - \$7500}{5 \text{ years}} = \$13,500/\text{yr.}$$

$$Z: \frac{\$175,000 - \$17,500}{5 \text{ years}} = \$32,000/\text{yr.}$$

Square-Footage Charges:

Case	Annual Charge	Yearly Sq. Footage		Amortization/sq.ft.	
		a: 5 shifts	b: 15 shifts	a: 5 shifts \$/sq. ft.	b: 15 shifts \$/sq. ft.
X	\$ 9,000	380,000	1,150,000	2.4	0.8
Y	\$13,500	1,250,000	3,800,000	<u>1.1</u>	<u>0.35</u>
Z { .012		6,250,000	18,000,000	0.5	0.18
	.016	4,000,000	12,000,000	<u>0.6</u>	<u>0.27</u>
	.025	3,500,000	10,500,000	<u>0.9</u>	<u>0.30</u>
	.040	2,500,000	7,500,000	<u>1.3</u>	<u>0.43</u>

II - D, Continued

f) Total Square Footage Processing Costs:

Cost in Cents per Sq. Ft. of Facings:

Item:	Batch		Coil			
	X	Y	.012	.016	.025	.040
Adhesive	0.9	0.9	0.9	0.9	0.9	0.9
Chemicals	0.5	0.5	0.5	0.5	0.5	0.5
Labor	3.6	2.9	0.3	0.45	0.5	0.7
Utilities	0.8	0.2	0.05	0.07	0.08	0.1
Burden	7.2	4.4	0.6	0.9	1.0	1.4
Amortization	2.4	1.1	0.5	0.8	0.9	1.3
Total Cost	15.4	10.0	2.9	3.6	3.9	4.9
Burden	5.4	3.3	0.4	0.7	0.8	1.1
Amortization	0.8	0.35	0.18	0.27	0.30	0.43
Total Cost	12.0	8.15	2.33	2.89	3.08	3.56

It should be noted that the costs (and savings) shown here represent half of the costs of processing facings for one square foot of sandwich.

These estimated costs show that a coil-processing system offers significant economies over batch methods. These savings are in addition to those which can be realized by purchasing and shearing aluminum in the coil form (a prerequisite in coil-processing and an alternative in batch processing).

It may be concluded that a continuous cleaning and priming system will be technically and economically justified when: (1) coiled heat-treated, aluminum becomes available in widths up to 48 inches and (2) when there is sufficient demand for cleaned and primed sandwich facings.

It is anticipated that both of these conditions may be realized by 1957 or 1958. (Parts of the design of the continuous-coil processing unit proposed in this project may be obsolescent at that time, and the cost of this type of equipment may change in the interim.)

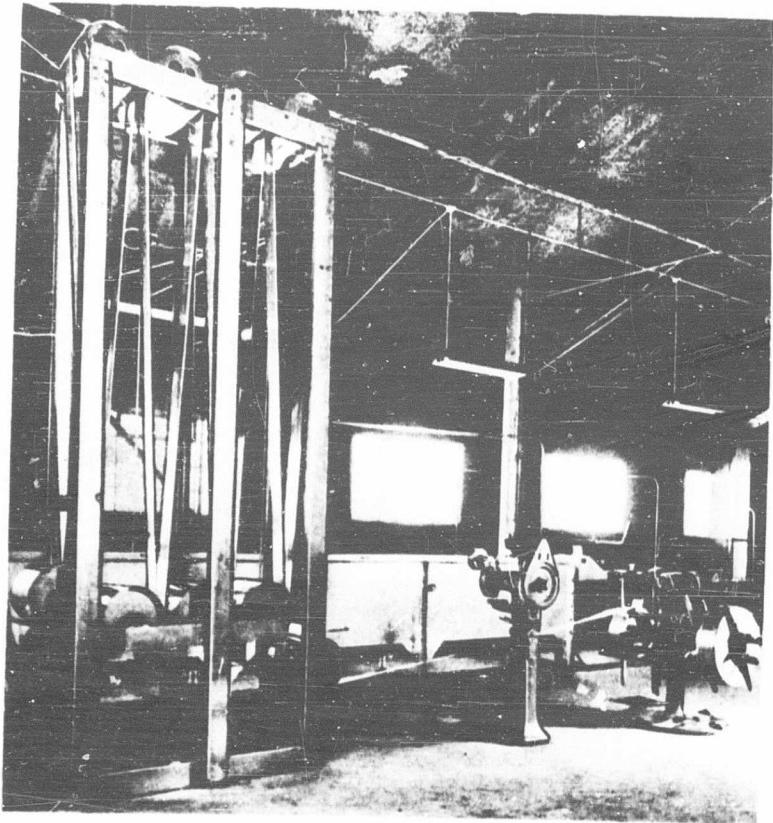


Figure 66: Accumulator, stitcher and double-reel uncoiler in typical strip painting line.  
(Photo courtesy Gasway Corp.)

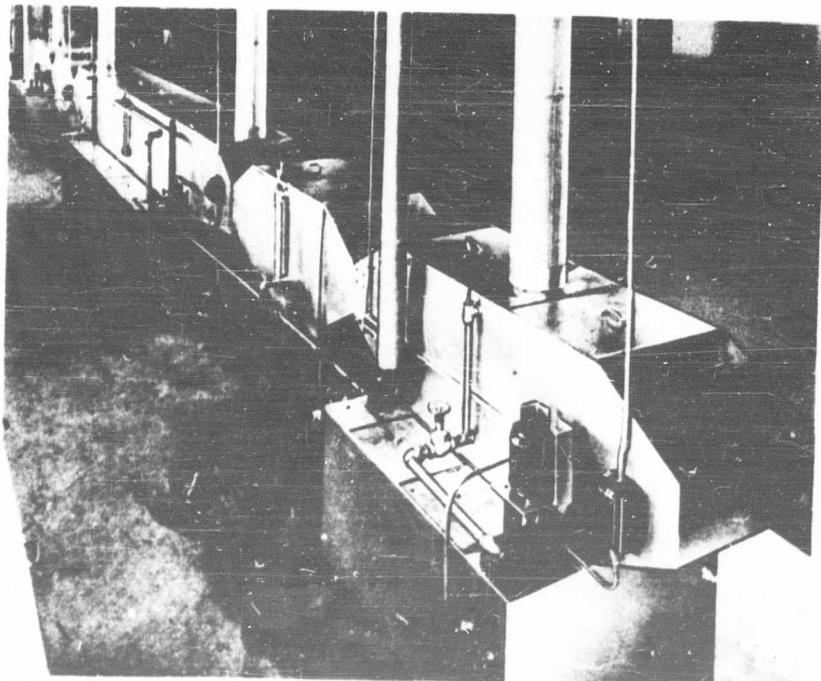


Figure 67: Spray washers and rinses in typical strip painting line. Note web emerging from squeegee rolls at right. (Photo courtesy Gasway Corporation)

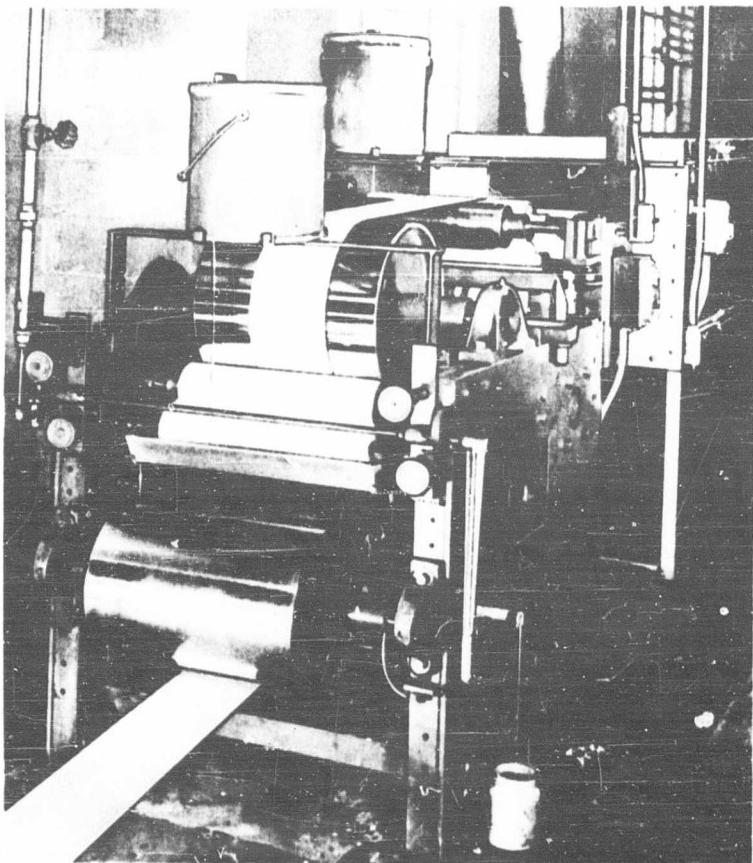


Figure 68: Double paint coater in typical aluminum strip painting line. Coated web enters continuous drying oven at upper right. (Photo courtesy Gasway Corp.)

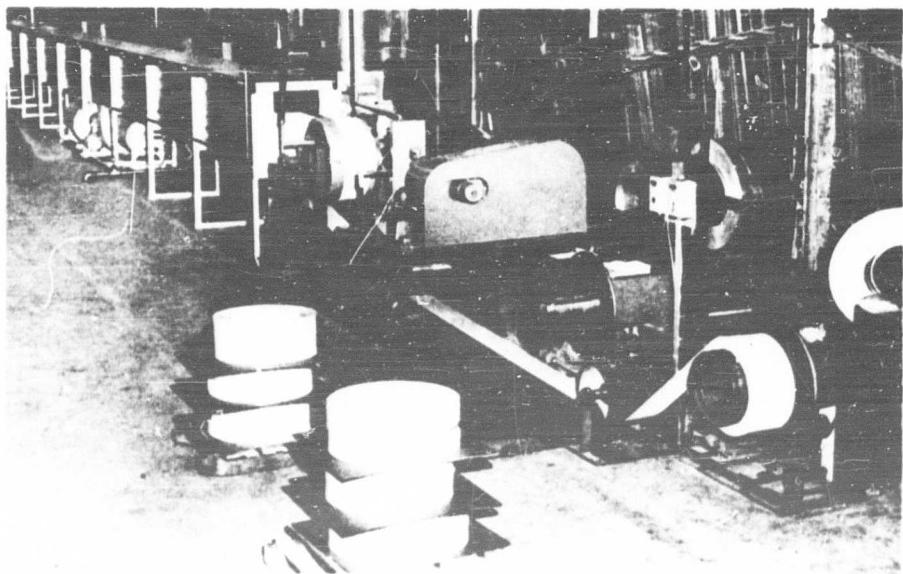


Figure 69: Oven, cooling rolls, drive and rewind spools in typical aluminum strip painting line. (Photo courtesy Gasway Corp.)

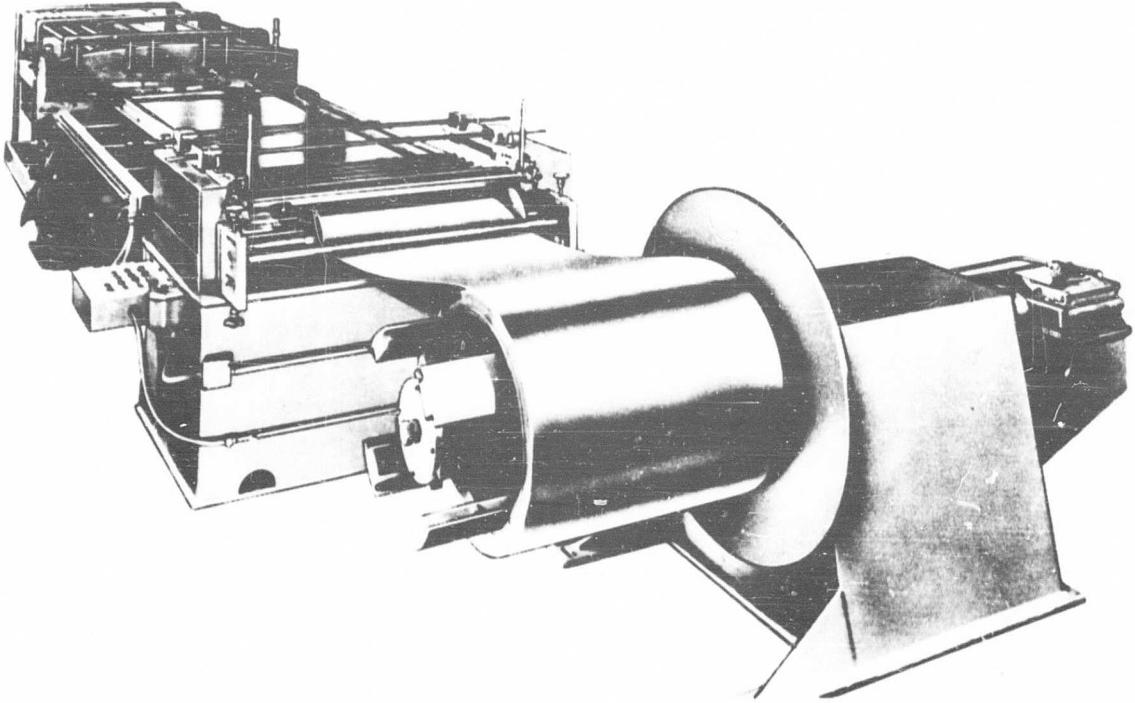


Figure 70: Coil shearing and stacking line. (Photo courtesy Dahlstrom Machine Works, Inc.)

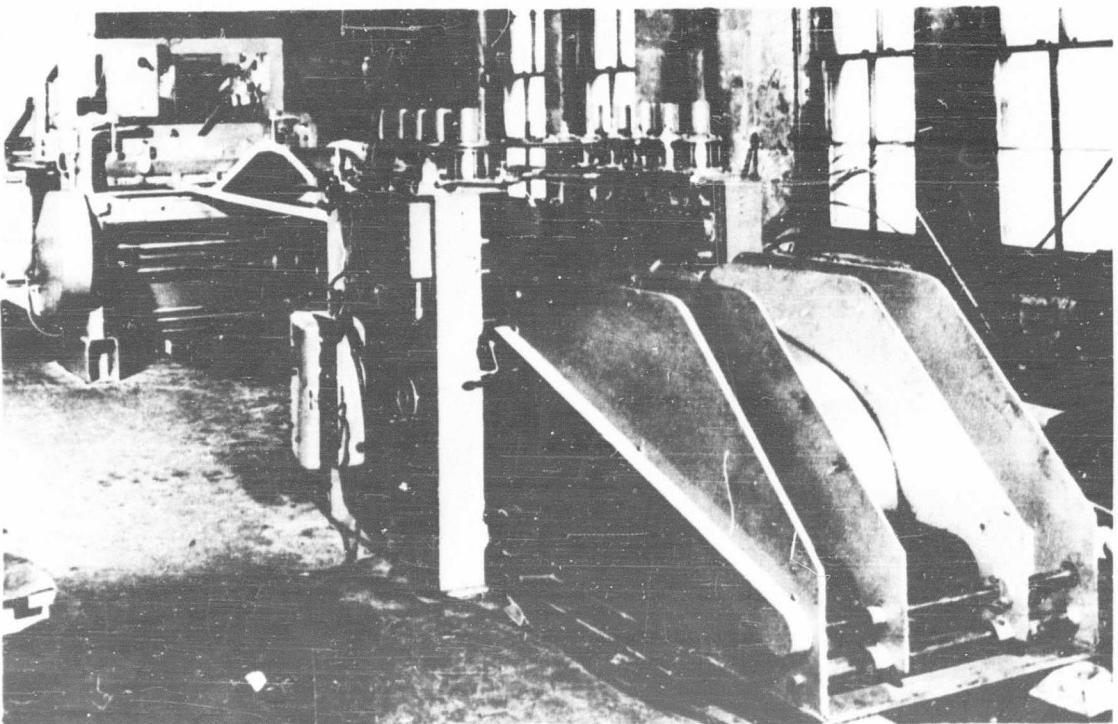


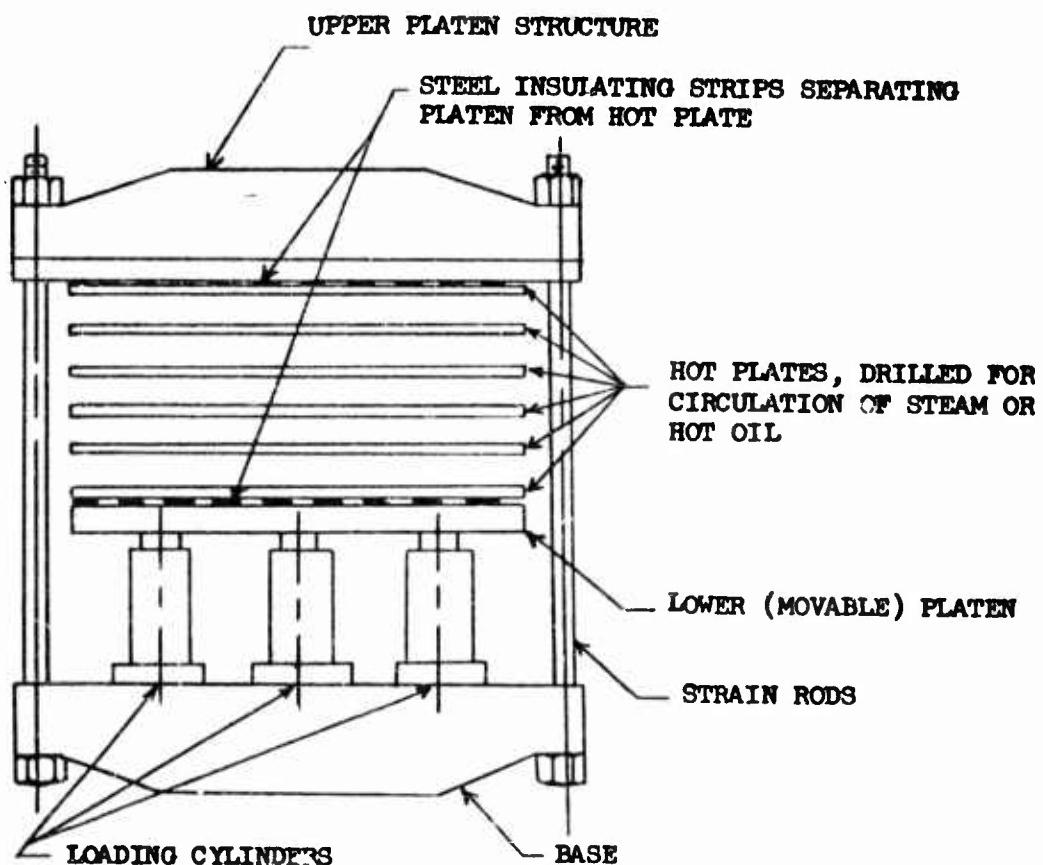
Figure 71: Coil shearing and stacking line. Shown here with cradle-type unwind stand; spool-type stands may be substituted. (Photo courtesy Union Tool Corp.)

SECTION II, Continued

E - CURING PRESSES:

Most flat sandwich is cured in "heated-platen" or "hot-plate" presses of the same general types used in making plywood. These presses sometimes give unsatisfactory results in honeycomb-sandwich bonding because of a lack of parallelism in their openings. This problem causes the same type of difficulties as are caused by core-thickness irregularities, but cannot be relieved by improving core-thickness tolerance, and can be only partly relieved by inserting resilient padding materials on either side of the sandwich composite.

The following simplified sketch of a typical five-opening hot-plate press presents the nomenclature used in this discussion.



It should be noted that the hot-plates themselves are sometimes referred to as "platens", but this is not the preferred nomenclature. Platens are ordinarily unheated, rigid structural members -- unless the hot plates and platens are combined into one structure, in which case the entire unit is called a "heated platen".

II - E, Continued

General survey information obtained early in the project indicated that variations in the press openings over the working area in sandwich bonding presses might exceed 0.030 inches in some cases. The error was generally attributed to thermal warpage, rather than to lack of precision in construction. The thermal errors were caused primarily by temperature gradients in the rigid frame and backup components of the presses, and were transient in nature over the first eight to 24 hours of operation after heatup. It was known that presses were often "shimmed" to correct the errors. The transient nature of the error suggested that shimming was not a satisfactory solution, since flatness in a press which had been shimmed at temperature equilibrium would not be assured in the interim period between the time the press reached operating temperature and the time of equilibrium. Some sandwich manufacturers felt that total warpage error was divided evenly among the openings in multiple-opening presses, reducing its harmful effects.

The development of special curing fixtures utilizing fluid pressure, transmitted through flexible or semi-flexible envelopes, was first considered. It was recognized that fluid pressure envelopes are advantageously employed in the bonding of some contoured primary structural parts, but they present as many technical and operational problems as are encountered in ordinary heated presses. Since heated presses represent a durable class of machines with which both builders and users have accrued much experience, and since they are widely used in the bonding of flat sandwich, it was decided to concentrate on the improvement of this type of curing fixture.

The first step was to devise a procedure for determining deviations from parallelism in the openings of sandwich bonding presses. In the first method tested, lead wires were laid two inches apart across the lower hot plate of a laboratory press. It was found that the press had to be at temperature to produce any deformation at all in the wires. The wire deformations in one laboratory press having flexible loading rams showed an average gradient of 0.010 inches down the length of the press. The exact cause of this gradient was not determined, but it was obvious that the gradient did not exist under actual curing conditions. In order to simulate a flat, incompressible panel surface and remove the indeterminate effects of lead wire compressibility, a pattern of aluminum stops 0.051 inches thick was laid out, and short pieces of 0.090-inch (diameter) lead wire were placed at definite intervals throughout the pattern. This method appeared to give a true indication of the press parallelism which would exist where the panel under cure was perfectly uniform in thickness. (It should be observed that the method did not reveal the flatness of the plate surfaces. "Parallelism," in the sense used here does not necessarily imply flatness of the surfaces or straightness of the opening.)

## II - E, Continued

The proposed "lead-wire" method was tried in a large production press, and refinements in the procedure were made. This investigation culminated in the following recommended procedure:

### 1. General:

It is desirable that two tests be run; one as the press just reaches operating temperature, and another after a period of at least 16 hours of continuous operation. It is desirable to run additional tests to simulate conditions under which undersize panels are bonded. Two men are required for each test, for a period of about 1/2 hour, including five minutes of press time.

### 2. Materials:

- (1) Aluminum stops, 0.051 inches thick, 10 inches long, and 1/4 to 1/2 inches wide.
- (2) Lead wire, 0.090 inches in diameter, cut into pieces 1/2 inch long.
- (3) Two cauls in good condition.
- (4) Micrometer.
- (5) Marking Pen.
- (6) Steel tape.

### 3. Method:

- (1) Mark off a rectangle corresponding to a typical panel size on the cleaner of the two cauls.
- (2) Lay out a pattern of 0.051" thick aluminum stops within the rectangle. Although the configuration is arbitrary, a "checkerboard" of open rectangles is most convenient. The sides of the rectangles should be from 12 to 18 inches in length. An additional stop should be placed diagonally in each rectangle to prevent local distortion.
- (3) After the stops have been laid out, place a 1/2 inch long piece of lead wire at each rectangle corner and at the center of each rectangle. If the wires are kinked before they are put in place they will not tend to roll when the caul is lifted.
- (4) Place the second caul carefully over the wires and stops. Insert the two cauls in the press. (Caution: In lifting the cauls take care not to allow them to sag or open up.) Apply curing pressure.

(5) Remove the cauls after approximately five minutes. Lift the top caul gently, and carefully invert it before laying it down.

(6) Measure the wire thicknesses with a micrometer, recording them on a preliminary diagram.

(7) Subtract the smallest thickness reading from all of the readings. Enter these differences on a final diagram. Note the conditions of the test (pressure, temperature, date, etc.).

Copies of the recommended procedure were furnished, along with quantities of pre-cut lead wire and stops, to a number of honeycomb manufacturers, with the request that they return copies of the results.

Results from three large (4 ft. x 8 ft. or greater) presses were obtained in response to this survey. Those who performed the test indicated that the method was satisfactory. The following diagrams represent the results:

PRESS NO. 1 (Two openings, 50 psi, 300°F, loaded by hydrostatic pressure in 8 parallel fire hoses between bed and lower platen. Platen insulated from lower hot plate with "Transite"):

1.5	3	1.5	1.5	1.5	1.5	3.5
<u>6</u>	2	4	1	1	2	
5	3.5	1.5	1	1.5	2	5
4	0	4	1.5	1.5	1	
3	2	0	2	2	2	4
1.5	2	<u>6</u>	3.5	4		
2	1	2	5	5	4.5	

THOUSANDTHS OF ONE INCH

II - E, Continued

PRESS NO. 2 (Two openings, 60 psi,  
300°F for at least 24 hours):

2	4	4	4	2.5	3
	4	<u>5.5</u>	4.5	4	
4	4	4	3	3.5	4.5
	3.5	4	2	2	
3.5	2	1.5	1.5	2.5	4
	3.5	2.5	1.5	2	
3.5	2.5	2	2.5	2.5	<u>5.5</u>
	0	3	2	2.5	
4	2.5	3	3	3	4

THOUSANDTHS OF ONE INCH

PRESS NO. 3 (One opening,  
300°F, 10 psi):

9	9	11	18	19	17	10	5	12
4	6	5	9	10	8	8	5	5
5	4	4	2	3	0	4	7	10
11	8	4	4	1	0	6	3	2
19	10	8	6	4	7	7	6	11
<u>23</u>	16	12	7	7	7	7	10	12

THOUSANDTHS OF ONE INCH

Presses Number 1 and Number 2 showed maximum errors of 0.006 and 0.0055 inches respectively, an acceptable degree of parallelism. The maximum error of 0.023 inches in press Number 3 shows a very poor degree of parallelism which could not be alleviated by the use of press padding materials. It is believed that press Number 3 may represent a condition which is not uncommon throughout the industry.

II - E, Continued

The next step in the program was to solicit advice from press manufacturers. A form letter of inquiry was sent to 27 firms, with a sample of sandwich material, and a diagram showing one proposed means of correcting the warpage problem. The letter explained the conditions of honeycomb sandwich manufacture and the contractor's conception of the warpage problem.

Several of the firms who were surveyed indicated either that they did not manufacture hot presses, or that their presses were too small for the application. The following press manufacturers responded with technical information regarding the design and operation of hot-pressing equipment. (This list does not constitute an endorsement of the qualifications of these firms, and undoubtedly overlooks some firms who are qualified to supply panel-pressing equipment.):

Baldwin-Lima-Hamilton Corp.  
2020 Nineteenth St.  
San Francisco 10, Calif.

G. Siempelkamp & Co.  
Krefeld, Germany  
Domestic Distributors:

Berthelsen Engineering Works, Inc.  
P. O. Box 1423  
Joliet, Ill.

Heyer Sales and Engineering Co.  
1003 Washington Bldg.  
Tacoma 2, Wash.

Fjellman & Winther Co.  
P. O. Box 1205  
Joliet, Ill.

Wilco Machine Works  
1301 North Hollywood St.  
Memphis 8, Tenn.

Merritt-Solem Division  
Solem Machine Co.  
Lockport, New York

Williams-White & Co.  
Moline, Ill.

Plycor Company  
(associated with Becker & Van Huellan)  
565 W. Washington St.  
Chicago 6, Ill.

R. D. Wood Co.  
Public Ledger Bldg.  
Independence Square  
Philadelphia 5, Penn.

Although some of the firms had supplied presses for honeycomb sandwich manufacture, most of them had not previously been aware of the flatness requirements involved. The majority of hot-plate presses are supplied for applications where precision requirements are much less demanding. All agreed that warpage was generally caused by thermal gradients in the rigid unheated components of the press. A number of simple modifications can be made in an ordinary press to reduce or eliminate the thermal warpage problem, and some presses are initially designed to produce very low warpages.

The thermal warpage in question is usually attributable to temperature gradients in the top and bottom platens, particularly the top platen. The underside of the top platen is hotter because of its proximity to the adjacent hot-plate, and as a result, the platen structure deflects downward. The loading of the press tends to bring about an opposite deflection upward, but the two deflections do not

II - E, Continued

necessarily cancel one another. An upward thermal deflection may occur in the lower platen structure in the same manner. The hot plates themselves are usually machined steel plates, approximately two inches thick, with drilled passages for the heat-transfer medium. Their high area-to-thickness ratio, and the fact that they are drilled, make them relatively flexible and low in strength.

The platen surfaces in a conventional press are insulated from the hot plates, usually by steel strips. Although the steel strips are relatively inefficient as an insulator, their thickness can be controlled very precisely, while most conventional thermal insulating materials are too soft and too low in strength to be satisfactory. Special high-strength materials have been developed specifically for the insulation of hot presses, but these materials have not gone into wide use at this writing. Shim stock is often inserted under the insulating strips, to compensate for known deviations from parallelism.

It is a matter of common knowledge in the press industry that the dimensional stability of any press can be improved by reducing or stopping the flow of heat from the hot-plates to the platens. One method of accomplishing this is to insert an additional drilled plate between the platen and its adjacent hot plate, for the circulation of cooling water. Steel-strip insulation must be added to both sides of the additional plate to prevent chilling of the hot plate and to prevent platen warpage resulting from variations in the temperature of the cooling water. When a water-cooled plate has been added, it is sometimes necessary to compensate for the additional heat loss, by using two heated plates instead of one. This modification is ordinarily carried out at the top platen only, but is sometimes done at the bottom platen as well. The introduction of water-cooled plates substantially reduces transient and steady-state heat flow to the rigid platens and allows the press to be shimmed to a stable degree of mechanical and thermal flatness.

Some presses are designed to minimize thermal warpages without using coolants. Usually this involves combining the platen and adjacent hot plate into one rigid structure which is heated uniformly, top to bottom.

The sketch at the beginning of this discussion, shows a press of the "strain rod" type, in which the pressing load is resisted by four corner posts. In another type of press frame, the bed, strain-rods, and upper platen reinforcement are replaced by a number of large, parallel plates, bolted or welded together with spacers in between. A rectangular opening is made in the plates to receive the platens, hot-plates and loading mechanisms.

Regardless of the design, the prospective press buyer should obtain some indication or guarantee of the magnitude of mechanical and thermal deflections in a given press. For ordinary flat sandwich bonding the contractor has concluded that a press should maintain a parallelism within limits of the order of 0.005 inches at any time after reaching operating temperature, and should not deflect more than 0.015 inches in each 100 inches of length under a full-area load of 100 psi.

A press in which uniform loading is approached or approximated is more stable dimensionally. A system utilizing eight or more hydraulic rams in two banks, and in which the rams can be used selectively, is recommended where undersize panels are likely to be bonded. Ordinarily, undersize panels are likely to induce undesirable end deflections which sometimes endanger the press itself. It is very advantageous to be able to use only the four rams in the center on half-size panels. The alternative to this safeguard against excessive deflection is to place "stops" near the ends of the press openings, a practice which can cause faulty pressure distribution arising from the difficulty in selecting stops of proper thickness.

It is essential that presses which are to be used for honeycomb sandwich bonding have a smooth and uniform action in closing. Some presses are provided with "compensators" to prevent the platens from closing unevenly as a result of the binding action of the ram cylinders.

Five to ten openings would be desired in a press which is to be used for the high production of flat sandwich parts. The maximum number of openings is limited by the combined weight of the floating hot plates in lbs. per square inch of full press area. This figure represents the pressure differential between the top and bottom panels in the load, assuming full-size panels. The pressure applied to undersize panels as a result of this dead weight would naturally be greater. The lighter honeycombs have bare flatwise room temperature compressive strengths of the order of 100 psi. Assuming a factor of three to allow for concentrations of load and loss of strength at elevated temperatures, the maximum allowable pressure on the bottom panels should be approximately 30 psi. Assuming that 10 psi should be the pressure applied to the panel in the top opening, in this range of density, the maximum differential caused by the weight of the plates should be no more than 20 psi. If "half-size" panels are assumed, the combined weight of the "floating" components should be no more than 10 psi, over the total press area.

It can readily be seen that if a multiple-opening press is closed immediately on a new load of panels, the bottom panel will be subjected to a pressure far in excess of that usually recommended for a conventional "pre-heating" period. If it is felt necessary to preheat the panels at "contact" pressure, a special loading schedule must be observed. The press must be closed slowly enough to allow the bottom panel to receive the weight of one floating hot plate at a time, at appreciable intervals. As the weight of each new plate is brought onto the panel, the effective pressure then rises in a stepped gradient. With suitable control equipment, the top press openings can be loaded while the lower openings (already loaded) are being closed, one at a time, by the rising platen. It is estimated that 15 seconds should be allowed for the closing of each opening. After the topmost opening is closed, the press may be allowed to stand at contact pressure in the top opening for a suitable period, after which full pressure would be applied for the duration of the cure. Whether this proposed loading cycle is used or not, the prospective buyer should determine whether the pressure control equipment being offered with the press will lend itself to the close control necessary here. Particular attention should be given to ability of the control system to reproduce and maintain very low pressures in the top opening.

Because of the danger of disrupting the normal filleting and coalescence of the adhesive bond, it would appear that presses should not be "breathed" or "cracked" during the cure. (This conclusion is not directly supported by experimental data obtained in the project.)

With the loading cycle proposed here, a "loading elevator" is a desirable accessory. Elevators of this type provide a platform of adjustable height from which workmen may slide the panels into the openings.

It is not recommended that press "stops" be used in the bonding of honeycomb sandwich panels. Stops are usually rectangular steel bars, which are placed around the edges of the panels to prevent crushing of the composite. The results of studies of the effects of curing pressure, and of core thickness irregularities, have indicated that the cumulative effects of thickness tolerances, warpages, mechanical deflections (including those in the padding material), and thermal expansions make it nearly impossible to select stops of appropriate thickness. A stop which is too thick prevents the panel from receiving adequate curing pressure, and one which is too thin does not prevent crushing. It is proposed that the use of stops be abandoned in favor of more fundamental methods of correction. These methods include the removal of thermal warpages from the press, the use of selective curing pressures on cores of various densities (10 to 100 psi are the recommended limits), the inclusion of a cloth in the adhesive line, and the use of resilient press-pad materials. Other sources of crushing problems which should be considered are the bonding of undersize panels, uneven or erratic closing of the press, and excessive core thickness variation. All of the factors mentioned here can be controlled.

An accurate temperature control system is required in a press which is to be used for adhesive bonding. One or more temperature recorders are mandatory accessories.

The addition of an automatic loading table, on which new panels can be laid up while others are being cured, is a refinement which is probably not justified with the long curing cycles involved in adhesive bonding. Usually, only two openings can be utilized where loading tables are used.

Many advantages and features offered by competing press manufacturers have not been discussed here, but should be given due consideration in choosing a press.

The use of aluminum cauls approximately 1/4-inch-thick is recommended in the curing of sandwich. The cauls must be larger than the parts themselves, and should be clean and free from dents, kinks, and edge-burrs. The thickness of the entire caul should be checked. (One press manufacturer reports that deflections in the rolling equipment sometimes bring about thick areas in the center portions of aluminum plates.) The bottom caul provides a convenient surface for laying up the composite, and the top caul is useful for holding the stack together while it is being moved. As the press is opened, the presence of the upper caul tends to retard chilling of the top panel facing, thus reducing thermal warpage of the panel. The cauls also help to protect the surfaces of the hot plates from damage.

II - E, Continued

In the survey of existing methods it was learned that precautions should be observed in cooling the panels as they are removed from the hot press, to prevent permanent thermal warpages. Panels should be withdrawn as soon as possible after opening the press to prevent undue chilling of one side. On removal, they should be stacked vertically with air spaces between, to provide free air circulation. (One manufacturer reports that if thick cauls are used, the panels may be safely cooled in stacks, with the cauls in place.

"Unsymmetrical" flat panels, in which one facing is thicker than the other, may tend to warp unless special measures are taken to adjust the insulating effects of the pads on either side.

Although some manufacturers are able to cure a number of panels in the same stack without any separation, others report that this practice induces permanent thermal warpage.

### SECTION III

#### SUMMARY AND GENERAL CONCLUSIONS

##### A. CRITERIA USED IN THE EVALUATION OF SANDWICH BONDS:

In the majority of test work conducted in this project, the four-inch-drum peel test and the flatwise tensile test were used to evaluate changes in the properties of sandwich bonds, as material and process parameters were varied. It should be emphasized that these two properties do not entirely determine the suitability of the bond in themselves. Inasmuch as there is some disagreement in the industry with regard to the selection of physical tests for qualification, quality control, and inspection purposes, some comments should be made here concerning the significance of various tests.

###### 1. Flexural, or Plate-Shear Tests:

A sandwich bond must generally be capable of sustaining the same magnitude of shearing stress as is required to fail the honeycomb core material. The shear strength of the bond, at the temperature in question, is influenced by the choice of the formulation and the conditions of fabrication.

Shear tests on sandwich structures are limited in the sense that they do not indicate the magnitude of the shearing strength in the bond, when the core material is subject to failure. For this reason, flexural shear tests, applied for quality control purposes, can only be depended upon to indicate the level of quality of the bond up to the point of core failure; beyond this point, the magnitude of the bond strength remains unknown. It is difficult to determine by visual inspection whether the bond or the core has failed first in a flexural shear test.

In the flexural shear test, the thickness of the facings and the core material and the conditions of the test influence the apparent magnitude of the core shear strength to an extent which is not predicted by the simplified shear formula. For this reason, a plate shear test is considered more definitive; however it is generally felt that a flexural shear test imposes more realistic conditions of loading and is much easier to perform.

###### 2. Flatwise Tensile Tests:

The work in this project has indicated that there is some correlation between the shear strength in the bond and the flatwise tensile strength in the bond, but that a fixed correlation exists only where adhesive formulation, test temperature, and (probably) the effective degree of cure are held constant. Since flatwise tensile tests can usually be relied upon to give an indication of the level of shear strength within the bond, under conditions in which the core material would be subject to failure in a shear test, tensile tests are desirable for quality control. It should be noted

### III - Continued

that the flatwise tensile strengths (and shear strengths) developed in the bond are a function of cell size, the configuration of the bond, and the fabrication conditions used in making the bond. It should be further noted that flatwise tensile strengths in sandwich bonds do not vary in the same way as do "lap-shear" strengths, as temperature is increased.

#### 3. Peel Tests:

The peel strength of a sandwich bond is an indirect measure of ability to resist impact loading; the life of the structure under fatigue loading; and ability to restrict the propagation of local failures at over-stressed or unbonded areas. Unless peel strengths are high, parts may be subjected to damage from careless handling or from subsequent finishing operations. No minimum peel-strength standards for design or qualification have been universally accepted by the airframe industry at this writing. On secondary structures, a "four-inch-drum" peeling torque of 40 inch-lbs. on a three-inch-wide specimen has been used by several airframe manufacturers as a minimum acceptable standard. Minimum peel strengths of 60 inch-lbs. or more have sometimes been specified on primary structures. Some primary sandwich structures having peel strengths as low as 30 inch-lbs. have successfully met service requirements, but it is possible that comparatively low peel strengths such as these are safe only when the particular adhesive formulation has compensating features such as high flatwise tensile strength. It should be observed here that peel testing methods and devices have not been standardized throughout the industry, but a four-inch-drum test is the most universally used at this writing. The work in this project has indicated that peel strength is generally related to the weight, configuration, and fabrication conditions incorporated in the bond. Peel strengths may sometimes be in a critically low range under extreme (high or low) temperature conditions.

#### 4. Edgewise Compressive Tests:

Although the strength of sandwich panels in edgewise compression is often an important design criterion, tests on laboratory-size specimens do not necessarily give a reliable indication of the structural integrity of the part, or of variations in quality, in production. In a small, flat, accurately machined, specimen containing no core splices, the facings can usually be expected to sustain compressive stresses which are in excess of the yield strength of the metal. The results are generally insensitive to the strength of the facing-to-core bond, in the normal range of bond strengths. Although the integrity of the structure may be strongly influenced by flatness irregularities, arising from core-thickness differences at splices, typical conditions of this type cannot be conveniently reproduced in small specimens. The criticisms of edgewise compressives mentioned here do not necessarily apply to "tall-column" compressive tests.

#### 5. Creep Tests:

Creep strength forms an important criterion in the selection of sandwich bonds, particularly where service temperatures are high and loads are long in duration. It is probable that the creep resistance of a given

### III - Continued

formulation is more critical in sandwich bonds than in continuous-surface bonds, and that it is more directly affected by the degree of cure given to the part. Although no creep tests were run in this project, some elevated-temperature tensile tests were run, and these tests may give an indirect indication of creep resistance.

#### 6. Lap-Shear Tests:

At this writing, military specifications based on lap-shear properties are still used as a criterion in the selection of adhesives for honeycomb sandwich bonding. Only a limited correlation exists between lap-shear strengths and honeycomb sandwich shear strengths, however, because of the basic differences between the two types of bonds. The percentage of room-temperature shear strength retained in a sandwich bond at a given elevated temperature is less than that retained in a lap-shear bond with at least one adhesive.

### B. CONSIDERATIONS IN THE FABRICATION OF SANDWICH PANELS HAVING CONSISTENT AND OPTIMUM BOND STRENGTHS:

Four basic stages in the fabrication of an aluminum honeycomb-sandwich panel are: the selection of materials; the preparation of the metal surfaces for adhesion; the application of the adhesive; and the bonding process itself. A number of conclusions, relating to each of these stages, are presented as follows:

#### 1. Selection of Materials:

In selecting a suitable adhesive system for a given structure, the most important criterion is the ability to develop the full strength of the core material and facings. The formulation should preferably be available in the form of a fabric-supported film as well as a liquid. The use of a supported film simplifies the production of the parts and improves the consistency of the quality of the end product. The presence of the cloth reinforcement upgrades peel strength (particularly where "low-modulus" formulations are used) and imparts some resilience to the composite during the application of curing pressure.

The liquid form of the adhesive in question should be in a range of viscosity that makes it suitable for the mechanical roller coating of core material. Its solid content should be as high as possible, within the permissible limits of viscosity. It is desirable that solvents in the adhesive have an evaporation rate low enough to prevent appreciable changes in viscosity during the coating operation.

For maximum economy in the utilization of curing fixtures, the curing cycle required to develop optimum properties should be as short as

### III - Continued

possible. It should be noted that longer curing cycles are generally required for sandwich bonds than are required for continuous-surface bonds made from the same formulation.

Since the weight of adhesive represents a significant percentage of the total weight of the structure, the cost of adhesive materials is a very important consideration in the selection of a suitable formulation for sandwich structures.

It is very desirable that a honeycomb-sandwich adhesive have sufficient flow at the curing temperature to produce a filleting action, resulting in an efficient distribution of adhesive.

The selection of materials for sandwich facings involves structural considerations which were not within the scope of this project.

The primary criterion in the selection of a suitable honeycomb core material is usually its ability to sustain the shearing stresses arising from flexural loading. In some cases, a honeycomb may be selected for its ability to sustain compressive loads. Most of the physical properties developed by honeycomb are primarily a function of its density in pounds per cubic foot, and are not directly related to cell size. Cell size is important, however, in that small-cell cores develop higher bond strengths under given adhesive bonding conditions and tend to impart maximum local stabilization to thin-gage facings that are loaded in compression. Small-cell cores in the lowest density ranges have one disadvantage, in that the light foils used in their construction make them susceptible to damage from handling.

In general, a "vented" or "perforated" core material should be used, to allow the escape of released volatiles during the cure.

The thickness tolerance maintained in flat honeycomb is of primary importance in determining the consistency of bond quality over the surfaces of the panels, particularly where several individual honeycomb and detail components are joined together in the same composite. A tolerance of  $\pm 0.005$  inches is adequate to insure a reasonable degree of consistency throughout the panel where a supported film of significant thickness is incorporated in the bond and adequate pressure distribution is maintained in the curing operation.

The method by which the honeycomb has been manufactured is usually not a consideration in its application as long as reasonable and careful conditions of manufacture have been maintained.

The degree of adhesion developed at the surface of the core material may be downgraded by long storage (of the order of one to four months) in an exposed condition. The material should be wrapped or enclosed during storage if priming cannot be performed within a reasonable period of time.

### III - Continued

Honeycomb core materials should not be cleaned unless they are known to be contaminated by storage or by lubricants applied in machining processes. Aqueous cleaning upgrades the properties of the core-to-face bond where the core has become contaminated, but reduces the strength of the node bonds.

#### 2. Preparation of the Facing Materials for Adhesive Bonding:

Facings must always be cleaned, and the cleaning process should be in an optimum range of control if high bond strengths are to be consistently maintained, and if the full resistance of the bond to exposure effects are to be developed.

As far as is known, an optimum degree of preparation of the surfaces of facings can be attained only by the use of an acid treatment subsequent to the removal of nonmetallic impurities in a degreasing operation. Hot, inhibited, alkaline cleaning compounds give satisfactory degreasing results and do not present critical control problems. The best known and least critical acid treatment is a hot solution composed of sodium dichromate and sulfuric acid. Sodium dichromate tends to inhibit the solution, while the sulfuric acid accelerates it. The concentrations of both chemicals should be maintained close to their original values by replenishment.

Where this solution has received extended use, the effectiveness of preparation of the surfaces for adhesion tends to become inconsistent and there is some danger that a scale deposit may form on the surfaces, or that the surfaces may become pitted. Chloride ion in the solution is not responsible for the aforementioned condition, but causes severe corrosive attack of a different nature when present in excess.

Corrosive attack and the formation of deposits are more likely to occur on thin sheets, and are accentuated by high acid temperatures and long immersion times. Although these conditions may be avoided by the use of short acid-immersion times or lower acid temperatures, the adhesion developed at the surfaces is likely to be downgraded as a result of changes. Since it is likely that conditions of this type may be influenced by local water impurities, it is inadvisable to recommend acid-treatment process schedules without taking this factor into account. In some localities the use of distilled water in the acid charge is undoubtedly justified. Where there is no danger of surface attack, an immersion time of ten minutes in conjunction with acid temperatures ranging from 145°F to 160°F can be expected to develop optimum adhesion. It should be noted that shorter immersion times may sometimes have to be employed on sheet thicknesses of the order of 0.012 inches, to prevent scaling or corrosive attack.

The acid solution recommended here would be suitable for use in a continuous-coil processing unit. The nominal temperature of the solution would be maintained at 160°F, to allow relatively short immersion times to be used. Immersion time would be inversely proportional to web speed, which would be varied selectively according to thickness and alloy.

### III - Continued

A warm rinse ( $140^{\circ}\text{F}$  max.) should preferably be used after the alkaline treatment. The rinse after the acid treatment may be warm ( $140^{\circ}$  max.) or cold. A cold rinse develops slightly higher adhesion, but warm rinses are advantageous in that they reduce subsequent drying time.

Cleaned facings may be stored as long as a week before priming without endangering bond strength, if they are not exposed to adverse contaminating conditions. It is advisable to prime as soon as possible after cleaning, however.

#### 3. Application of the Adhesive:

A prime coat of adhesive should be applied to the facings to protect the cleaned surface, to promote adhesion, and (probably) to develop maximum resistance in the bond to deterioration from exposure. The weight of the face prime is not critical so far as bond strength is concerned. The use of a dye in the prime solution provides a satisfactory means for determining if coverage is complete. The degree of pre-cure given to the prime is also not critical, but the durability of the coating prior to panel layup is enhanced by extended precures.

The best-known production method for applying primes to individual sheets is spraying. Where the facings are processed in the coil form, roller coating may be used.

Both the weight and the depth of the core prime influence the level of strength developed in the bond. Primes should be applied to the core material at a shallow depth (0.025 inches, approximately). A light prime coat of unspecified weight, applied in one pass through a roller coater, and used in conjunction with a moderately heavy tape, would represent the best compromise between production economy and structural integrity when it is not necessary to develop maximum bond strengths.

A viscous, resinous adhesive can best be applied to flat honeycomb as a light prime by power roller-coating. A blade metering system is far superior to a roll metering system for this purpose.

In order to avoid the necessity of handling the primed, undried slices of core material, it is desirable that a continuous-oven drying system be used in conjunction with the coater.

For reasons described elsewhere in this section, it is highly desirable that a fabric reinforcement be incorporated in the bond, preferably through the use of a "supported" film so that the major part of the adhesive in the bond can be applied in a predetermined, consistent amount.

#### 4. Curing:

A multiple-opening, "hot-plate" press is the most desirable tool for the production bonding of flat sandwich parts. Some of these presses display a lack of parallelism in the openings due to temperature gradients

### III - Continued

in their rigid structural components. Most non-parallel presses can be restored to acceptable accuracy by certain modifications. Where the precision requirements are known in advance, a high degree of parallelism can be supplied in new equipment.

The effects of thickness irregularities in the composite, and of nonparallelism in the curing fixture, can be partially relieved by the use of resilient padding materials.

Selective curing pressures ranging from 10 to 100 psi should be used on cores of various densities to develop optimum bond strengths without danger of crushing. The use of "stops" to prevent local crushing of the core does not appear to be justified, and may bring about a condition in which the bond receives no curing pressure at all. The weight of the "floating" components of a multiple-opening press imparts a significant additional increment of pressure on the panels in the lower openings.

The use of a short "preheat" period at contact pressure is probably justified on large, flat sandwich panels. Some adhesives having rapid hardening characteristics may be downgraded in strength by preheating.

The curing times, temperatures, and pressures recommended on continuous-surface bonds are not necessarily optimum for sandwich bonding. In general, pressures should be lower, while curing times and/or temperatures should be increased, on honeycomb sandwich parts.

#### C. APPLICATION OF MECHANIZED TECHNIQUES IN THE MANUFACTURE OF SANDWICH:

Survey and experimental results have indicated that it is undoubtedly feasible and highly desirable to clean and prime aluminum facings in the coil form. A processing line for this purpose would be patterned after existing pre-coating lines, and would cost approximately \$175,000.00. Facings could be processed in a line of this type at rates of the order of 16,000 square feet per shift, at a cost of 2 to 4 cents per square foot, including adhesive costs. This cost would be approximately one-third of the cost of most existing methods.

An additional saving of approximately 2-1/2 cents per square foot, not included in the above processing costs, would be realized through the purchase of facing material in the coiled form rather than in the form of flat sheet. This saving could be realized whether the material is eventually processed in the cut sheet form or the coil form.

None of these cost savings can presently be realized, since 48-inch-wide, heat-treated, coiled aluminum sheet in the thinner gages is not as yet available. It is expected that this type of material will become available within two to four years (1956 - 1958).

### III - Continued

In addition to offering direct and indirect savings in costs, processing in the coil form would permit facings to be produced in substantial lots. The quality of the aluminum surfaces and of the prime coating could be consistently and easily maintained, because of the removal of hand variables from the operations.

An interim method in the mechanization of cleaning and priming methods would be the processing of individual sheets in a manually-controlled, continuous-monorail cleaning system, followed by spray priming and continuous drying on a moving conveyor. This system would not offer complete freedom from the effects of hand variables, but would prepare facings at substantially higher speeds and lower costs than would existing batch methods.

The proposed system for priming large quantities of flat slices of honeycomb in a system combining a modified roller coater and continuous drying oven has already been mentioned. It is estimated that a system of this type would permit the cost of core priming to be reduced by approximately five cents per square foot. This estimate includes a saving in material cost, brought about by more efficient location of adhesive on the honeycomb.

Where large panels are produced in quantity, layup should be performed on some type of conveyor system. The cauls used in the pressing operation could be utilized as platforms to support the parts on such a conveyor.

The proposed mechanization techniques are described in more detail in appendices to this report, containing proposed high-production plant layouts and tentative specifications and drawings for the proposed core-priming and drying line and the continuous-coil processing line.

Estimates have indicated that total savings of the order of 25 to 40 cents per square foot of optimum quality sandwich can be realized by utilizing advanced mechanized equipment in conjunction with high production rates. These total savings include individual savings of as much as ten cents per square foot in the cleaning and priming of each facing and five cents per square foot in the priming and drying of the core material. Other savings included in the total are those brought about by lower inspection costs, more efficient utilization of curing fixtures, lowered rejection rates, and the lay-up of panels on a conveyor system. The reduced costs estimated here are based on the assumptions that optimum process conditions (curing times, acid-immersion times, etc.) are upheld, and that the production rate would be of the order of 5,000 square feet of sandwich per shift. The majority of individual cost savings could not be realized unless high production rates justified the procurement of the specialized equipment. The procurement of the equipment would be technically justified, however, on the basis of the improved quality level of the end item, even if a low utilization rate prevented significant cost savings from being realized.

### III - Continued

#### D. MAINTENANCE OF THE CONSISTENCY OF QUALITY OF FLAT SANDWICH STRUCTURES:

It appears that some of the effort which is normally expended in the continuous, destructive inspection of flat sandwich parts can be more gainfully used in the maintenance and control of fabrication conditions. Where flat sandwich panels are produced at high production rates, it is mandatory that the need for inspection and testing of finished panels be minimized to avoid the production of numerous reject panels before process and material variations can be detected. The dependence upon final inspection can be reduced by the application of advanced production methods and adequate material and process control. Correlations of material and process variables with defects in finished panels, of the type determined in this project, are required to establish practical control conditions.

The application of mechanization and high-production techniques simplifies the maintenance of the quality of sandwich parts by transferring the control of process variables from the workmen to automatic devices. It can easily be seen, for example, that the inspection of cleaned and primed facings from a coil-processing line can be based upon peel-test results from only a few specimens, removed from the ends of each finished coil. The level of quality exhibited by these specimens gives a reliable indication of the quality of the entire coil, whereas specimens would have to be removed from each rack-load of sheets in a batch cleaning process to give a comparable degree of assurance that quality was being upheld.

There has been no indication in the work in this project that the inspection and testing of raw materials used in the panels should be curtailed.

Four major production factors which affect the quality of the bonds in finished sandwich parts are: preparation of the facings; weight and configuration of the bond; curing cycle; and curing-pressure distribution. Since a number of these factors affect the consistency over the entire panel surfaces as well as from panel to panel, destructive tests from local areas do not necessarily reveal all the defects. The use of a practical non-destructive test which could be applied over the entire surface of each panel would be of great benefit as a final check on production quality.

It is proposed that adhesion conditions at the facings be controlled at the cleaning process, not upon completion of the production panels. Peel tests run on special heavily bonded sandwich specimens in conjunction with periodic chemical analysis can be used to isolate and quantitatively describe the adhesion conditions at the adhesive-to-facing plane.

Since a multiple-opening steam-heated or oil-heated press gives dependable temperature control, and since continuous automatic "temperature-vs.-time" records can be made as the panels are bonded, only periodic physical

### III - Continued

tests are required to check degree of cure on high-production flat panels, once the control limits of the cycle are established.

Adhesive-weight conditions in the tape influence the bond strength but can be ascertained before the tape is used. The weight of a light core prime is not easily determined, but the improved control which is available from the proposed core-priming unit, in combination with the additions of dye to the stock, would allow inspection to be on a visual basis in the majority of cases. To this end, it is desirable that panels be designed to require only one roller-coating pass on the core material, wherever structural necessity does not dictate that maximum bond strengths be obtained.

The work in this project indicated that one of the most important tools for isolating the cause of low strength results was the analysis of the "type of failure". Although low peel strengths often suggest to the manufacturer that the cleaning process may be out of control, there is no basis for a conclusion of this type unless an unusually high percentage of the peel failure has taken place in adhesion at the facing. It is regrettable to note that records of the type or location of failure are not always maintained in laboratory and quality-control work involving the destructive evaluation of adhesive-bonded assemblies.

There is no doubt that some amount of destructive physical testing must be conducted "after the fact" to maintain control over the entire process. Valuable data can often be obtained from integral test coupons when these are available from panel cutouts or other representative trim areas. The tabulation on the following page shows some of the correlations between types of defects and process variables which have been observed in the project.

III, Continued

Correlations Between Defects and Process Conditions:

Change in Process Condition Causing Defect:			Defect Manifested In:								Conditions Under Which Process Variable Is Critical:
Increase	Decrease	Variable:	Tensile Strength	Peel Strength	Elevated-Temp. Strengths	Corrosion Resistance	#	Outer Appearance	Compressive Strength	Fluid Immersion	
x	x	Core or insert thickness	x	x	-	-	x	x	x	-	Several pieces used in same panel
	x	Press flatness	x	x	-	-	-	-	x	-	All cases
	x	Core-prime weight	x	x	-	-	-	-	-	-	Tape weight low
	x	Tape weight	x	x	-	-	-	-	-	-	Core-prime weight low
x		Age of acid solution	-	-	-	x	x	-	-	-	High acid temperature, light gages, long time
x	x	Core cleanliness	x	x	-	(x)	-	-	-	-	Light bond, large cell
x		Mean curing pressure	-	-	-	-	-	-	x	-	Light cores
x		Mean curing pressure	x	-	-	-	-	-	-	-	Heavy cores
	x	Acid temperature	-	x	-	(x)	-	-	-	-	Acid content low or dichromate high
	x	Sulfuric acid concentration	-	x	-	(x)	-	-	-	-	Low acid temperature, high dichromate conc.
	x	Acid immersion time	-	x	-	-	-	-	-	-	Low acid temperature
x		Dichromate concentration	-	x	-	(x)	-	-	-	-	Low acid temperature
x		Curing temperature	*	*	x	-	-	-	-	x	Short curing time
x		Curing time	*	*	x	-	-	-	-	x	Low temperature
x		Effectiveness of alkaline cleaner	-	-	-	(x)	x	-	-	-	All cases

\* Probably depends on adhesive

\*\* Parentheses indicate that condition is probable only; not based directly on results from project.

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## APPENDIX I

### CONTROL FABRICATION METHODS AND MATERIALS USED ON TEST PANELS

#### a) General:

In order to condense this report, the control procedures used in fabricating all test panels are discussed in this appendix. Deviations from the control procedures, where they are thought to be significant, are detailed in the presentations of individual evaluations.

Although the control fabrication methods established early in the contract were thought to be near optimum, later evaluations proved that some were not. In many cases, control methods were revised after individual evaluations had indicated that the conditions were in a critical range.

A close control over all parameters was sought in the fabrication of each panel, but human errors and equipment failures sometimes occurred. Where any doubt as to correct fabrication technique existed, individual panels or groups of panels were rejected from the results. Where the inconsistency appeared to be the result of a variation in an overly critical parameter, the parameter was studied as an independent variable.

#### b) Materials:

##### (1) Facings:

Facings used in this project were purchased as full-sized sheets and were cut to nominal size by an outside source. The control facings (alclad 24S-T3, 0.016 inches thick) were purchased in several lots from the same manufacturer, but may have represented several mill runs. Aluminum sheet in other gages and alloys varied as to manufacturer.

In shearing the facings and incorporating them into panels, the orientation of the "rolling direction" was not noted. A check performed at the close of the project revealed that the rolling marks on almost all facings were oriented in the "peeling" direction.

##### (2) Core:

The control core material was of the "expanded" type, cut 0.625 inches thick, with vent-holes in the cell walls. Cores were ordered in a number of lots over a period of a year. Storage precautions and the duration of storage were not entirely consistent. The majority of core slices were cut to size, weighed, and wrapped in kraft paper for storage, as soon as received.

Appendix I, Continued

At the outset of the project, a control density of the order of 4 to 5 lbs. per cubic foot was arbitrarily selected. It was soon discovered that this density was too low to resist the flatwise tensile loads (and in some cases, the peeling loads) which were encountered in some of the heavier bonds. A control density of the order of 6 lbs. proved to be generally adequate, but would not sustain the high tensile loads required to fail heavy adhesive bonds on 1/8-inch-cell-size cores. A nominal density of 8 lbs. per cubic foot had to be used in these cases. This density was also used in the majority of the multiple-tape panels, which were designed to fail at the adhesive-to-facing plane.

Although the densities of individual pieces of honeycomb core were recorded, this information has not generally been presented with the results, or used in interpreting them. Density is primarily a function of the true cell size (or "cell count") and of the aluminum foil thickness. It is doubtful that foil gage has a large effect on bond strength, but cell size has been found to have a striking effect. Since minor variations in cell size were not recorded, and since density itself does not necessarily give an indication of cell size, bond strength results could not be corrected for physical variations in core material. It is probable that the over-all dispersion of bond strength readings in the project would have been reduced had actual cell size been taken into account.

The following is a tabulation of the aluminum cores used in the project (all cores were of the "perforated" or "vented" type):

<u>IDENTIFICATION</u>	<u>DENSITY</u>
1/8-.0015	6.1 lbs/cubic foot
1/8-.002	8.1 lbs/cubic foot
3/16-.002	5.7 lbs/cubic foot
1/4-.003	6.0 lbs/cubic foot
3/8-.004	5.4 lbs/cubic foot

(3) Adhesive:

The adhesive used as a test vehicle in all facing-to-core bonds was "FM-47". Relatively small lots of liquid adhesive thinner and supported film were purchased from time to time from two different sources. No attempt was made to determine if individual quantities of liquid adhesive were chemically consistent, but all rolls of supported film were cut up and weighed. Wrinkled areas, or areas which showed large weight gradients locally, were set aside and used in noncritical location, or else scrapped. The selection of an adequate number of uniform and consistent tapes of the same unit weight for each evaluation proved to be a major problem. For practical reasons, it was necessary to assume all batches to be chemically consistent, and to place emphasis on weight consistency. There was no evidence in the work to indicate that the liquid or the film, from either source, was chemically inconsistent.

Appendix I, Continued

The following unit weights applied to tapes used in the project. (Actual variations have been estimated from weight records.):

<u>Designation</u>	<u>Nominal</u>	<u>Actual</u>
"extra light" (special run)	0.03 lbs./sq. ft.	0.024 ± 0.002
"medium"	0.05 lbs./sq. ft.	0.05 ± 0.01 - 0.007
"heavy"	0.07 lbs./sq. ft.	0.07 ± 0.015 - 0.01
"extra heavy"	0.079 lbs./sq.ft.	0.079 ± 0.004
"Four pass" (special run)	0.086 lbs./sq. ft.	0.086 ± 0.003
"Five pass" (special run)	0.098 lbs./sq. ft.	0.098 ± 0.004

Other adhesives encountered in the project are discussed individually in the text of the report.

c) Panel size:

The majority of the earlier panels were nominally ten inches by eighteen inches in size. This size was chosen because it was believed necessary to obtain four three-inch-wide peel specimens and four flatwise tensile coupons (one inch square) from each panel. Later, it became apparent that two peel specimens were adequate, but that the number of tensile coupons should be increased to six or eight. These requirements allowed the panel size to be reduced to nine inches by nine inches. No densified areas, inserts, or edgings were incorporated in any of the panels, and none of the panels exceeded 10 inches by 18 inches in size.

d) Panel Identification:

A "panel history" sheet was prepared with each panel fabricated. This form contained space for the recording of all material variables, pertinent weights, special process techniques, and test results. The autographic peel records were clipped to the back of the "history" sheet and the completed histories were filed by consecutive serial numbers, which were given to the panels chronologically as they were bonded.

e) Weighing:

A careful accounting of all individual and cumulative adhesive weights was maintained on most panels. Core-prime weights were measured by weighing the core slices before and after they were primed and dried. (The "unit weight" used here was the total weight of applied adhesive on both sides, divided by the area of one side.) "Force-dried" unit weights of adhesive were recorded on primed facings. The unit weight of each piece of supported film used in the project was recorded. Where the unit weights of two tapes in the same panel were significantly different, peel tests were run on the light side only, and the total cured-

Appendix I, Continued

adhesive weight of the panel was corrected to a value which assumed both tapes to be light. "Total cured adhesive weight" was determined by weighing the panel components before and after cure, and subtracting this difference from the total weight of the uncured adhesive components. Since this procedure consistently gave a ratio of "cured" to "uncured" adhesive weights of about 0.85, the uncured weight was often multiplied by this factor in lieu of subtracting the weight lost in curing.

f) Core Priming:

Although a few special cores were primed by hand methods (roller, brush, or edge dip), the majority of cores were primed to a given number of passes in a roller coating machine. Cores primed early in the project were processed in a 1/4-H.P. "light-duty" veneer coater (bottom coating only from rubber-covered applicator roll, doctored by a steel roll; both rolls in an underslung pan reservoir). A schematic of this coater is shown in Table 27 at the end of Section II, Part A. Figure 75 at the end of this appendix shows this coater in operation.

Later in the project, "control" cores were primed in a small, hand-driven coater having the same general roll configuration as the power machine. Photographs (Figures 51 and 52) of this machine are contained in Part B of Section II, in the description of skin priming evaluations.

A control doctor setting of 0.030 inches was maintained on all core coating runs in which prime depth was not an independent variable. This setting gave a depth of penetration which varied locally from approximately 0.010 inches to 0.035 inches when the power-driven coater was used. Late in the project it was determined that the hand-operated machine had given a lower range of core-prime depths than the power-driven machine, at the same (0.030-inch) doctor-gap setting. This condition was found to result from the fact that the doctor roll on the smaller machine was not immersed in the reservoir. Although every attempt was made to keep the depth of prime consistent, actual depths were very difficult to measure, and the consistency of the peel and tensile results were undoubtedly influenced to some extent by variations in core-prime depth.

In priming individual slices, one side was first given a definite number of successive passes, with no significant interval between each pass. The slice was then air dried for about 15 minutes, and the same number of passes was applied to the other side. The consistency of the prime coats obtainable from either machine was relatively poor, for experimental control purposes. The use of the improved "doctor-blade" metering system would have brought about a substantial improvement in control, but this development was not completed until the majority of the cores for use in the test panels had already been primed.

Appendix I, Continued

g) Cleaning of Facings:

The control methods used in preparing facings, where the preparation itself was not an independent variable, changed several times in the course of the contract. Originally, the following schedule applied to facings:

- (1) Ten minutes' immersion in inhibited alkaline cleaner ("OAKITE '61'", 4 oz./gal.) at  $180^{\circ} \pm 5^{\circ}\text{F}$ .
- (2) Hot spray rinse for three minutes.
- (3) Five minutes' immersion in a hot ( $140^{\circ} \pm 6^{\circ}\text{F}$ ) air-agitated solution of the following components:  
1 part sodium dichromate  
10 parts concentrated sulfuric acid  
30 parts water.
- (4) Hot spray rinse for three minutes.
- (5) Force drying in warm air (fan-type electric heater) for ten to thirty minutes.
- (6) Removal from racks and wrapping in kraft paper until priming operation (max. two hours' storage).

Later work indicated that five minutes' immersion in the acid, at  $140^{\circ}\text{F}$ , was a relatively critical process condition, in which peel strength of panels having heavy adhesive lines was sometimes sensitive to variations in time and temperature. In most of the evaluations of individual variables, facing cleanliness was not a critical factor, as evidenced by the absence of failures in the interface between the adhesive and the facing. Where either deterioration of the cleaning solutions or sensitivity of the control process conditions appeared to have been capable of influencing the results of any individual evaluation, the results are noted with this information.

Several intentional changes were made in the control cleaning cycle during the course of the project. The alkaline cleaning concentration was raised to 6 ounces per gallon. Later, the type of inhibited cleaner was changed from "OAKITE '61'" to "OAKITE '61-A'". There was no evidence of a change in physical properties as a function of alkaline cleaning. The durations of the rinsing times were lowered and a cold rinse was substituted for a hot rinse, after the acid treatment. An improved thermostat was added at the acid tank, bringing the temperature variation down to  $\pm 4^{\circ}\text{F}$ . About midway through the project, the procedure was amended so that only the unlettered sides of the sheets were primed in every case. After the effects of acid-cleaning variables became established, all control facings were cold-rinsed for thirty seconds in a water spray at room temperature, rather than being rinsed for three minutes in a hot spray. Some lots of control facings, processed at the

## Appendix I, Continued

end of the contract, were acid-cleaned at 160°F for 3 or 3½ minutes, or at 140°F for 8 minutes. Since these cycles were known to be dependable, these lots were designated "best cleaning" or "optimum cleaning" in the descriptions of the control conditions.

### h) Priming of Facings:

All control facings were primed with a dilute solution of "FM-47" (one part of liquid at 20 pct. solids in one part of "FM-47 Thinner" approximately). Two major changes in priming conditions were made in the course of the contract. In the first, "OIL-RED 'O'" (National Aniline), a red dye, was added to the priming solution to allow easier visual inspection. A comparison of "dyed" vs. "undyed" skin primes (see Part I) indicated that the dye had no apparent deleterious effect on bond strength.

In the second change, the brush-priming technique was modified to give a smoother coating and to prevent water-vapor absorption. Before the change, each facing had been brushed fairly rapidly while at room temperature. The coating was then force-dried with a hot-air gun with a nozzle temperature of approximately 400°F. This method tended to produce a very uneven coating, which did not become obvious until after the dye came into use. It was believed that the adhesive coating might have been susceptible to water vapor absorption because of the chilling effect of solvent evaporation in the former method. In the revised method, the bare facing was warmed gradually with the hot-air gun, and then the prime was brushed on with slow even strokes. Force-drying with the gun was then performed as before. The resulting coating was very consistent and appeared to exhibit less tendency to "blush" from the absorption of water. The two methods were compared during the exploratory cleaning-variable evaluations, and no noticeable difference in peel strength was observed. There appeared to be much less local "scatter" in the auto-graphic peel records, however, after the improvement in coating consistency was made.

The use of a brushing technique is not recommended in preference to spraying for the priming of facings in production.

### i) Bonding:

All panels were cured in hot-plate presses. All of the 10-by-18-inch panels were bonded in a specially made press having 12-inch-by-20-inch electrically heated plates (See Figure 76, at the end of this section). Smaller panels were made in a 9-inch-by-9-inch commercial laboratory press. The latter press was considered somewhat superior in flatness, durability, and temperature control accuracy. In the last half of the project the smaller press was used exclusively.

Appendix I, Continued

Panels were bonded with sheets of aluminum foil and blotter stock on each side to give some degree of padding. The blotters were discarded after two or three bonding cycles. It is doubtful that uncontrolled flatness errors in the platens, or thickness errors in the honeycomb, had a significant effect on bond strength in the relatively small panels made in the project.

All control "FM-47" panels were cured according to the following schedule:

"Five minutes preheat at contact pressure (2 to 4 psi approximately) at  $345^{\circ} \pm 60^{\circ}\text{F}$ , followed by 55 to 60 minutes at 30 to 35 psi. (No release of pressure between preheat and cure.)"

This cycle is longer in duration and higher in temperature than that recommended by the manufacturers of "FM-47". It had been used as a control cycle by the contractor, before the project began, on the basis of an observed superiority.

The evaluations of curing variables have indicated that the known tolerated variations from control curing conditions did not have a significant effect on the consistency of the test results.

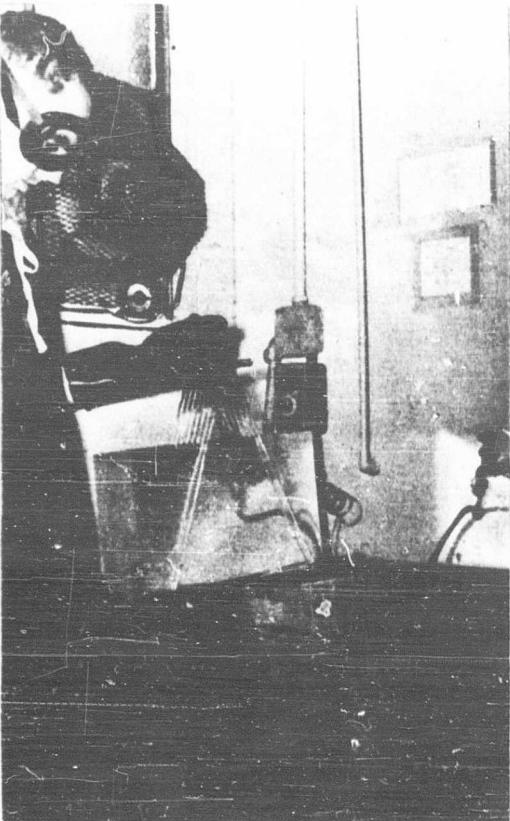


FIG. 72. ACID DIP

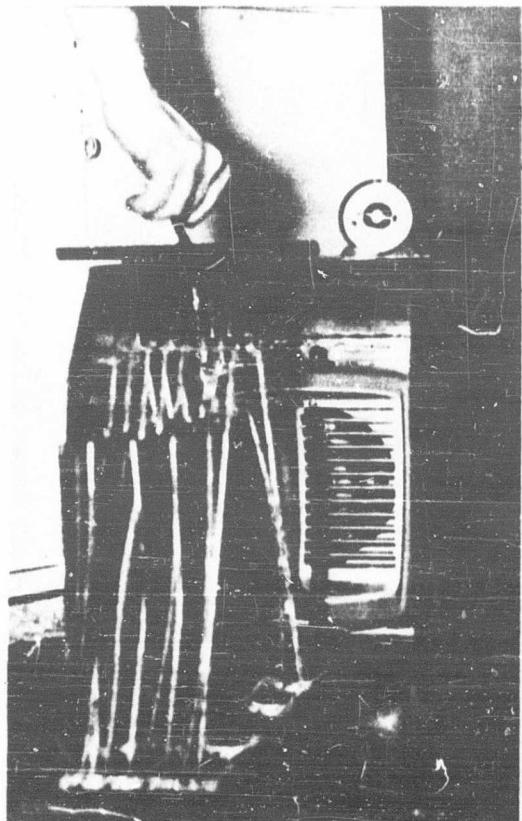


FIG. 74. FORCE DRYING

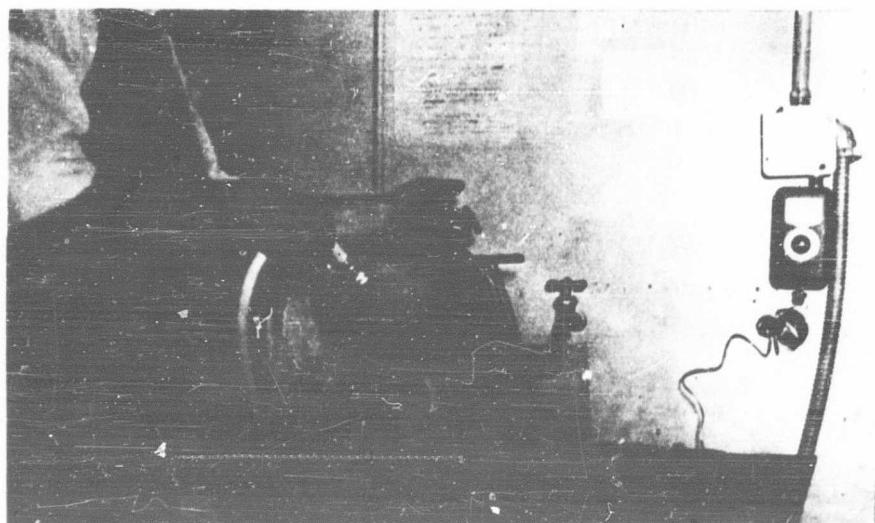


FIG. 73. HOT SPRAY RINSE. THREE STAGES IN THE  
PREPARATION OF SKIMS FOR PRIMING.

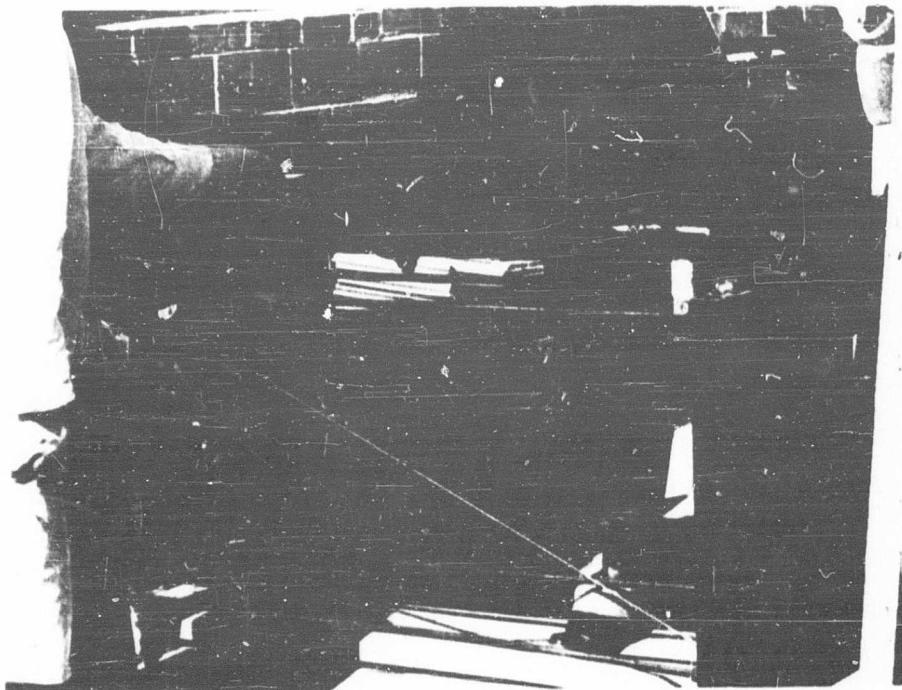


FIG. 75. PRIMING BOTTOM SIDE OF A 10" X 18" HONEYCOMB CORE SLAB IN A 52", 1/4 HP, GLUE SPREADER (SAFETY GUARD REMOVED).

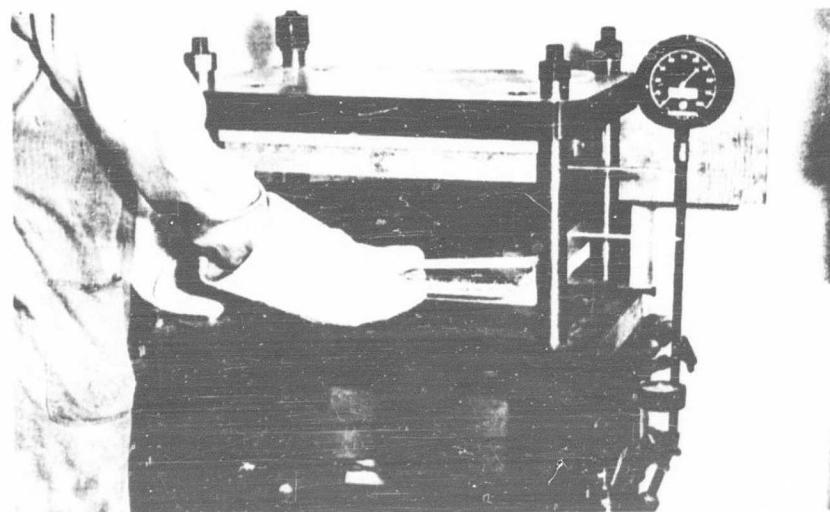


FIG. 76. REMOVING THE CURED 10" X 18" TEST PANEL FROM THE AIR-OPERATED PRESS.

## APPENDIX II

### TEST METHODS AND DEVICES USED IN PROJECT TO EVALUATE BOND STRENGTHS

#### a) Tests applied; general

The "four-inch-drum" peel test and the flatwise tensile test (one-inch-square specimen) were used to evaluate bond strengths in this project. Where the adhesion to the facing was the important dependent variable, the bond was tested in peel only. Flatwise tensile strength was found to be unaffected by the condition of the adhesive-to-facing bond. In certain instances peel and tensile tests were conducted at elevated temperatures.

Short-span flexural tests at room and elevated temperatures, and edgewise compressive tests at room temperature, were run primarily to determine if any fixed correlation with flatwise tensile strength existed. The conditions of these tests are reported in Appendix VI.

Where applicable, the test conditions and equipment set forth in Forest Products Laboratory's Report No. 1556, "Methods for Conducting Mechanical Tests of Sandwich Construction at Normal Temperatures", were utilized.

#### b) Size and number of specimens

Originally, it was believed that four one-inch-square specimens from each panel would give a satisfactory determination of the average flatwise tensile strength in the panel. The number of specimens was later increased to six or eight in the majority of evaluations, in order to increase the validity of the average. In most panels, the flatwise tensile coupons were removed from one or more one-inch strips, sawed from the approximate center of the panel, in a direction parallel to the peel specimens. In a few instances extra tensile specimens were sawed from the untested butt ends of the peel specimens. Special sawing schedules are noted in the results of certain evaluations.

All peel specimens were eight to ten inches long, and were sawed in the "ribbon" direction. In order to make it easier to clamp peel specimens in the fixture, the cores in most panels were cut slightly undersize, leaving a portion of the facings unsupported at each end of the specimens.

Where the adhesive bonds in each panel were known to be practically identical, peel tests were run on both sides of the panel, alternating from specimen to specimen. Where symmetry in the adhesive planes had been sought, but was not achieved, peels were run on the side which was believed to be the weaker.

All of the earlier peel-test results were based on four specimens cut from each ten-inch-by-eighteen-inch panel. The scatter of the peel readings proved that many of the panels contained strength gradients resulting from indeterminate local variations in parameters such as tape weight, core-prime weight, and curing pressure. A number of panels exhibiting inconsistencies of this type were rejected from the program.

Appendix II, Continued

It was decided that the rejection rate could be reduced and that better control over fabrication conditions could be established by making smaller panels. Accordingly, the standard panel size was reduced to nine inches by nine inches and two, rather than four, peel specimens were sawed from each panel. In reducing panel size and increasing the number of panels to compensate for the reduced number of specimens available from each panel, accuracy and reproducibility of the results were greatly increased.

It is strongly recommended that relatively small panels be used in all experimental evaluations of honeycomb-sandwich properties. This recommendation is particularly applicable where flexural shear strength, in either the bond or the core material, is the dependent variable. Parameters such as core density, prime weight, and tape weight should of course be observed and recorded after the component parts of the panel have been cut to size, to make maximum use of the data.

c) Flatwise tensile apparatus and testing procedure

The important design details of the modified flatwise tensile apparatus, which was a close copy of that detailed by Forest Products Laboratory in their report No. 1556, are shown in Figure 81 at the end of this Appendix. It was found that the rectangular cradles used in the FPL fixture were not strong enough to resist the loads that could be carried in "heavy-adhesive-line" bonds, and that it was difficult to achieve a straight pull through the centerlines of the specimens. The FPL cradles were designed with a 1-1/8-inch-square opening to receive the one-inch-square specimen blocks. In order to raise the strength of the fixture, this opening was made smaller, giving a close fit about the specimen block. The modification gave ample strength as a result of the increased wall thickness, and removed the need for centering each specimen in the cradle by hand. The diameter of the removable pins was increased from 1/4 to 3/8 inch and large knurled knobs were provided for ease of withdrawal in the oven.

The original apparatus had been clamped in the serrated jaws of the Tinius Olsen test machine. This clamping was replaced by providing rectangular plugs fitted to the dimensions of the tapered openings in the crosshead and the table of the machine. Longer pull rods were provided to accommodate the height of the removable testing oven. The bottom rod was rigidly centered in the crosshead by the plugs while the top rod was suspended centrally from a spherical nut-and-washer combination. The lower rod was connected to the grip by a ball-swivel joint. This joint allowed the grip to fall free as the failure occurred, thus facilitating the substitution of new specimens.

Each tensile specimen was band-sawed from the panel with a blade having 24 teeth per inch. The edges of the specimens were then deburred with a file, and the outer surfaces of the facings were lightly sanded to give a satisfactory bonding surface. The faying surfaces of the bonding blocks were cleaned on a belt sander, shortly before the adhesive was applied. Freshly prepared epoxy adhesive was then applied sparingly to the surfaces of both the bonding blocks and the specimens. In the first half of the contract, "EPON VI" was used to bond all tensile specimens to the test blocks. Where this adhesive was used, the coated surfaces were allowed to set up for about two hours before being wrung together and placed in an

Appendix II, Continued

oven for thirty minutes at 180°F. With the advent of tensile testing at elevated temperatures, it was decided that "EPON VIII" should be used because of its probable superiority at the temperatures in question. This adhesive did not require a "setting" period after coating. A curing cycle of 45 minutes, at 180°F, was given to tensile specimens cured with "EPON VIII".

Either of the two epoxy adhesives gave satisfactory results, as long as the specimens were made up correctly. Where too much adhesive was used, where only one faying surface was coated, or where the surfaces were not properly sanded, failures sometimes occurred in the block-to-specimen bond. These failures were not averaged in the results.

Where Shell's elevated-temperature adhesive, "422", was tested in flatwise tensile up to 500°F, the block-to-specimen bonds were also made with "422", to provide sufficient heat resistance. Before any specimens were laid up, several blocks were bonded together with pieces of "422" tape, under clamp pressure. It was found that only a small area in the centers of the one-inch-square surfaces would bond together satisfactorily. On checking the flatness of the block surfaces, it was found that they were "crowned" as much as 0.003 inches from the manual belt-sanding operation. The problem was eliminated by sanding six blocks at a time in the special frame (Figure 86). The size and mass of the frame allowed the operator to hold the blocks firmly and evenly against the sanding belt, and produced a very flat surface. The block-to-specimen bonds were intentionally undercured (15 minutes in an oven at 330°F) to minimize peeling of the core-to-face bonds. The elevated-temperature flatwise tensile tests were entirely successful; no failures occurred in the block-to-specimen bonds.

It was found that the useful life of the specimen blocks could be increased significantly if they were originally made 1-1/8 inches long instead of only one inch. They were discarded after successive sanding operations had reduced their height to 15/16 inches or less. The hole diameter was made 3/8 inches to receive the larger pins. A small additional hole was drilled through some of the blocks to accommodate a thermocouple lead during elevated-temperature tests.

Flatwise tensile specimens were pulled in the Tinius-Olsen machine at an approximate rate of 300 lbs./minute. A test was conducted to determine if this rate had any effect on the breaking strength, and if this effect could be used to give an indication of creep properties. Tensile coupons were cut from two panels made with adhesives which appeared to be susceptible to creep failure. The results, summarized in the following tabulation, did not indicate that the rate of pull had a significant effect on breaking strength within the practical rate limits of the machine:

Approximate Loading Rate lbs/min.	Observed Tensile Strength (avg. of 3 rdgs.)	
	Adhesive "X"	Adhesive "Y"
100	224	309
300	223	316
1000	211	318
10000	248	315

Appendix II, Continued

In certain instances where low-density honeycombs were used in panels, peel failures were observed to occur in both the core and the bond, within the same specimen. The outstanding feature about these failures was that the torque was a function of the type of failure, being very low in a region of core failure and high in a region of bond failure. In one panel made for the General Electric Company where a 1/8-.001 core was used, failure began in the core at a torque of approximately 45 inch-lbs. and abruptly transferred itself to the bond at a torque of the order of 180 inch-lbs. The co-existence of two types of failure, each manifesting a different strength, was also observed to a lesser degree in some specimens which failed in the bond only. In these specimens, the recorded torques appeared to be lowest where the failure had occurred in the closest proximity to the core.

In all of these instances, the failure appeared to transfer itself back and forth indiscriminately, and the probable degree of inconsistency in the strength of the panel over its surface did not account for the variations in peeling torque. The contractor believes the significance of the phenomenon is that peel failures which occur in the core are not necessarily an indication of panel quality, but are proof that the bond is adequate. The contractor does not know of any instances where honeycomb panels failed in peel within the core material, under service conditions.

The peeling fixture was used in elevated-temperature tests on several adhesives. The decomposition of bearing lubricants under heat determined the upper limit of test temperature. The tester in the project was used with ordinary lubricants up to 500°F on "422", but the bearings began to tighten up at about 400°F. The operator ran the tester without a specimen at both temperatures to determine the approximate frictional torque, and subtracted these readings from those taken with specimens in place. The bearings and the gear teeth had to be carefully cleaned and flushed with lubricant to restore free-turning operation after the test. The use of special high-heat lubricants would have extended the practical temperature limits of the machine.

In undocumented tests conducted on several rejected panels, peeling speed did not appear to affect the level of the peel torque. It did change the magnitude of the minor fluctuations on the traced record, however. Faster speeds tended to give the fluctuations less amplitude. In general, the machine as constructed had a significant inertia and tended to damp out minor torque variations without recording them. This limitation did not appear to be serious, however.

A phenomenon observed in the use of both the autographic peel-tester and hand-operated machine was the fact that narrow specimens gave

Appendix II, Continued

higher readings (in terms of inch-pounds per inch width) than did wide specimens. This tendency can be seen in the following tabulation:

<u>Panel</u>	<u>Nominal Specimen Width (Inches)</u>	<u>Number of Specimens</u>	<u>Peeling Torque Corrected to 3-inch width (Inch-lbs.)</u>
166 Machine-Peeled	1	2	187
	2	2	165
	3	3	147
168 Machine-Peeled	1	2	118
	2	2	93
	3	3	76
214 Hand-Peeled	1	3	147
	2	3	126
	3	2	128

This size effect may be attributable to transverse propagation effects, which are essentially independent of width.

At the time the peel tester was designed, there was some discussion as to whether or not the specimens should be "back-loaded" so that the facings would always lie tangentially against the drum at the line of failure. It was believed that the effect of facing thickness would be substantially nullified if the facings followed the drum as they came off the core. Furthermore, it would be possible to utilize nearly all of the specimen length in the average, whereas as much as six inches of length are sometimes wasted in the conventional machine. Since it was not known whether a practical back-loaded machine could be developed in time to be used in the evaluations of bond strengths, the conventional design was used throughout the project.

On one occasion a dead load of 50 lbs. was applied to a well-bonded 0.016-inch-thick facing through a temporary pulley fixture mounted on the autographic peel tester. In a specimen of this type the facing would ordinarily be pulled off almost vertically. There was a difference of only a few degrees in angle from the vertical attributable to the application of the back-load. It appeared that the amount of back-load required to hold well-bonded light-gage facings against the peeling drum might be very high. The additional tension produced by this amount of back-load might call for special clamping techniques, to prevent the specimens from pulling loose during the tests.

Although it would be desirable to cause the facings to follow the curvature of the peeling drum by back-loading or other means, the use of the conventional tester, without back-loading, gives readings which satisfy the purpose for which they are intended; i.e., to make comparisons of the strengths of bonds made to facings of one material and thickness. Practically speaking, comparisons may be made where facing thickness is variable, if the variations are within reasonable limits.

As each flatwise tensile specimen was broken, it was removed and the actual dimensions were measured with a machinist's scale. The indicated value of flatwise tensile strength was then corrected for area. The broken specimens were inspected by the operator and the type of failure was recorded. Usually, only one type of failure was in evidence. On "FM-47"-bonded panels the majority of tensile failures occurred in cohesion between the film and the cell walls. Panels made with large cell cores and/or light adhesive lines sometimes failed in adhesion to the core or, more commonly, in a mixture of adhesion and cohesion. The general absence of tensile failures between the film and the facing throughout the project supported the conclusion that the flatwise tensile test does not give an indication of the strength of the bond at the adhesive-to-facing interface.

The broken flatwise tensile specimens were not saved. Used blocks were heated briefly in a laboratory furnace set at about 900°F, and the epoxy adhesive was scraped away with a putty knife. The blocks were then ready for re-use after the belt-sanding operation.

d) Peel-test apparatus and testing procedure

Photographs of peeled specimens and of graphical peel records are shown in Figures 77 through 80 at the end of this appendix.

The four-inch-drum, machine-driven, autographic peel-test apparatus, shown in Figures 84 and 85 and in drawings F2, F3 (Figs. 82 and 83) was kinematically a copy of a fixture used in conjunction with a torque wrench. A number of specimens cut from the same panels and tested in both the manual and the autographic testers gave excellent correlations in their average readings. The autographic tester proved to be generally superior to the hand tester in reliability, range, ease of operation, and accuracy. One of its chief advantages lay in the fact that it could be used in tests at moderately elevated temperatures.

All peel specimens (with the exception of some from "non-destructive testing" specimens) were three inches wide and from eight to ten inches long. All the specimens were peeled in the "ribbon" direction. Although it is believed that peel strength in the ribbon direction is somewhat higher than in the direction across the ribbons, no tests were conducted within the project to determine the effect of direction. It has been learned from outside sources that peeling torque is also influenced by the rolling direction in the facings. Higher peels are said to be obtained when the rolling direction coincides with the peeling direction, but no attempt was made to confirm this.

Sawed peel specimens were identified by a panel number and a specimen letter. Each specimen was de-burred with a file and measured with a machinist's scale, before being clamped in the peeling fixture. The height of the gap between the peeling drum and the three rollers was adjusted so that the specimen would contact only the roller adjacent to the drum. (The other two rollers were nonfunctional and could have been left out.) A sheet of graph paper, rubber-stamped with an identi-

Appendix II, Continued

fication heading, was placed in the recording drum, under the typewriter rollers. The test machine was then zeroed and the recording pen was put down on the corner of the margins of the grid. With the indicator still at zero, the drum was rolled by hand so that the pen made a datum line across the page. The machine was then loaded to give a peeling speed in the range 2 to 4 inches per minute. After the peeling drum had rotated 90° (approximately 3½ inches on the paper) the action was considered to be at equilibrium, and a mark was made on the graph. (The portion of the graph before the "90°" mark was not averaged in the results). Marks were also made on the graph to indicate where the line of failure had passed over any line of demarcation, signifying an intentional change in fabrication conditions within the panel.

The peeling was stopped when the end of the specimen slipped over the last roller, or when the pen reached the end of the paper. The specimen and the graph were set aside and a new specimen and a blank graph were inserted. The mean height of the recorded torque curve was later observed, multiplied by a constant to convert it to inch-pounds, and corrected for specimen width. High and low torque readings as well as the mean were recorded. Some of the tabular presentations show low peel readings as percents of the mean, in order to give some indication of consistency of quality.

Peel results in this report are expressed in "inch-lbs. of torque per three-inch-width of specimen". In the Interim Summary Report, and in early progress reports, peels were expressed in "inch-lbs. per inch of specimen width". The magnitude of the latter reading was one-third of the former. The actual widths of the specimens were three inches in either case, and the choice of the larger figure was made on the basis of its greater degree of usage in the industry.

Peeled specimens were visually graded for type of failure in large batches. Six types of bond failures were recognized in a supported-film system. The first criterion applied to the side of the tape on which the failure occurred; that is, whether the tape remained attached to facing, or to the core material, as the facing was peeled off. The failure on either side was broken down into "adhesion", "cohesion", or "adhesion and cohesion mixed". In the tabular presentations, these failures are called "A", "C", and "AC", respectively. The percentage of area in which each type of failure occurred was recorded. In many peel specimens, all six types were observed. All specimens (approximately 2000 in all) were graded by the same person.

A modified system of peel failure observation was used on the "three-tape" panels. Here, all specimens were designed to fail in adhesion, or in a mixture of adhesion and local cohesion, at the facing; the occurrence of other types of failures made the results void. Mixtures of adhesion and cohesion on the facings were not graded as "AC" but were broken down separately. The recording of failures here was susceptible to arbitrary judgment, just as in the "six-failure" system, but the results tended to favorably augment the quantitative peel-torque readings.

Appendix II, Continued

It is sometimes suggested that the peeling torques required to bend facings of various gages be determined so that peel-torque readings made on the conventional machine may be corrected to give absolute indications of the adhesive forces in the bonds themselves. It has appeared, however, that the amount of torque required to bend the facings is a function of the adhesive forces in the bond besides being a function of the material and the thickness of the facings. Light-gage facings in combination with heavy adhesive lines tend to come off the specimen nearly vertically, with a very small radius of curvature at the failure itself. Heavy-gage facings and facings which are poorly bonded tend to follow the curvature of the drum. As far as is known, it is not practical to experimentally determine the torque absorbed by an unbonded facing, since little permanent bending is performed unless the facing is firmly attached to the core material.

PHOTOS OF PEELED SPECIMENS:

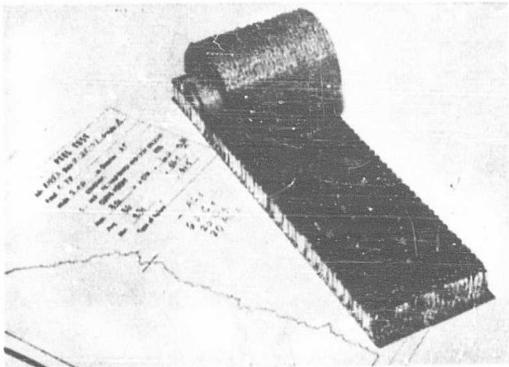


Figure 77: Predominantly cohesive failure, tape-to-core. This panel was made with primed 1/8-cell core, and "0.07" lb/sq. ft. tape. Recorded peeling torque: 168 inch-lbs per three inch width.

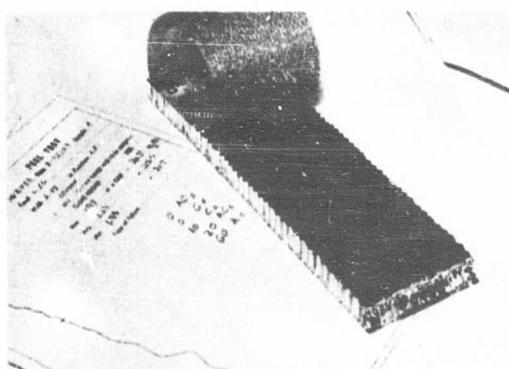


Figure 78: Adhesive failure between "0.07" tape and unprimed, 1/8-cell core. Recorded peeling torque: 78 inch-lbs.

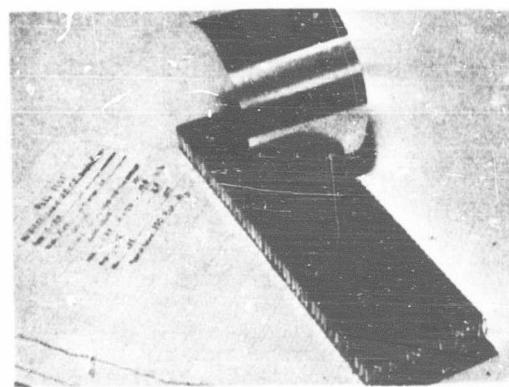


Figure 79: Adhesive failure to uncleaned alclad 24S-T3 facing 0.016 inch thick. Recorded peeling torque: 54 inch-lbs.

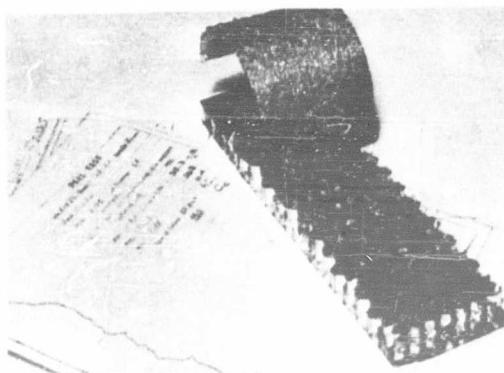
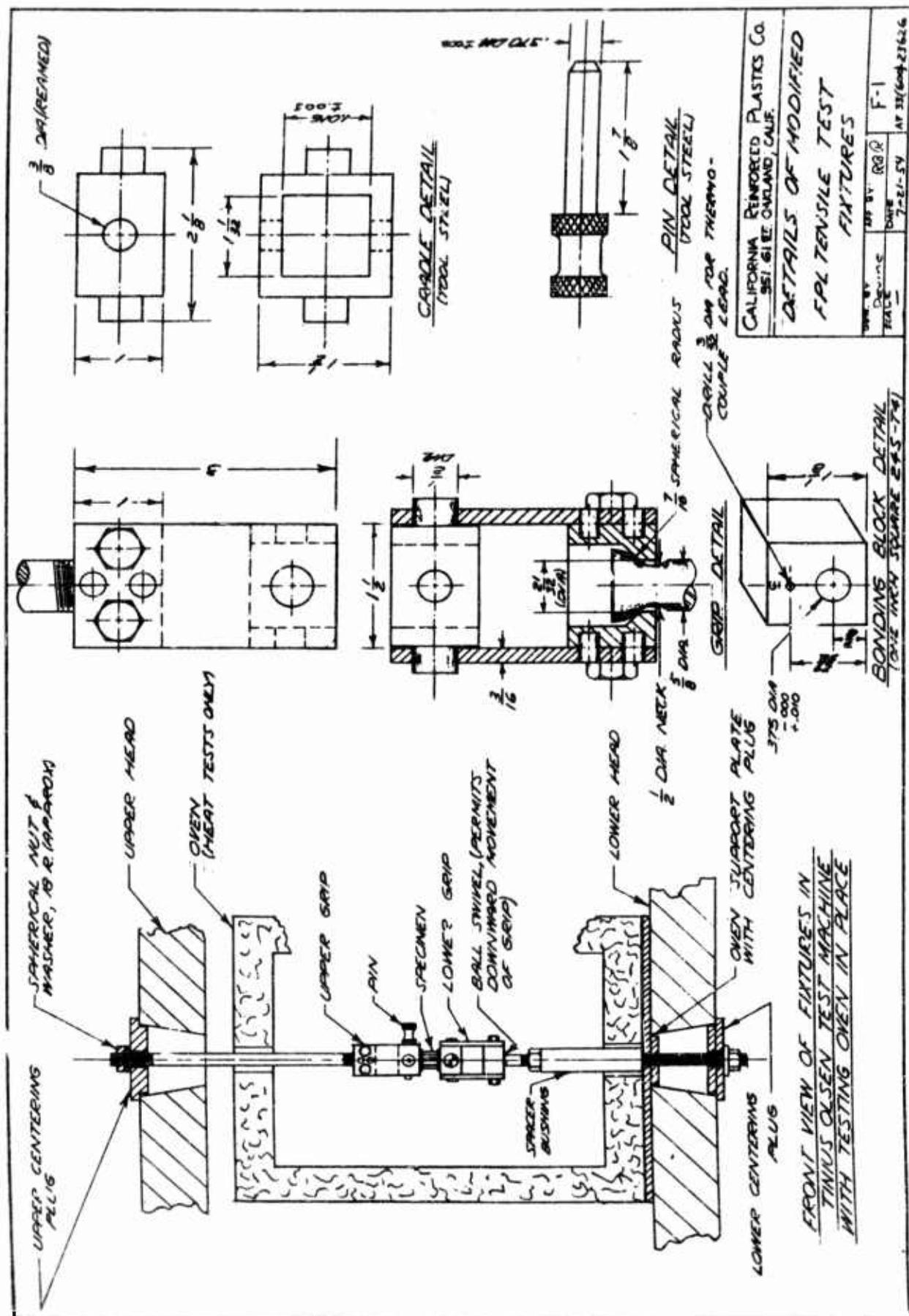


Figure 80: Predominantly cohesive failure between "0.07" tape and primed, 3/8-cell core. Recorded peeling torque: 69 inch-lbs.



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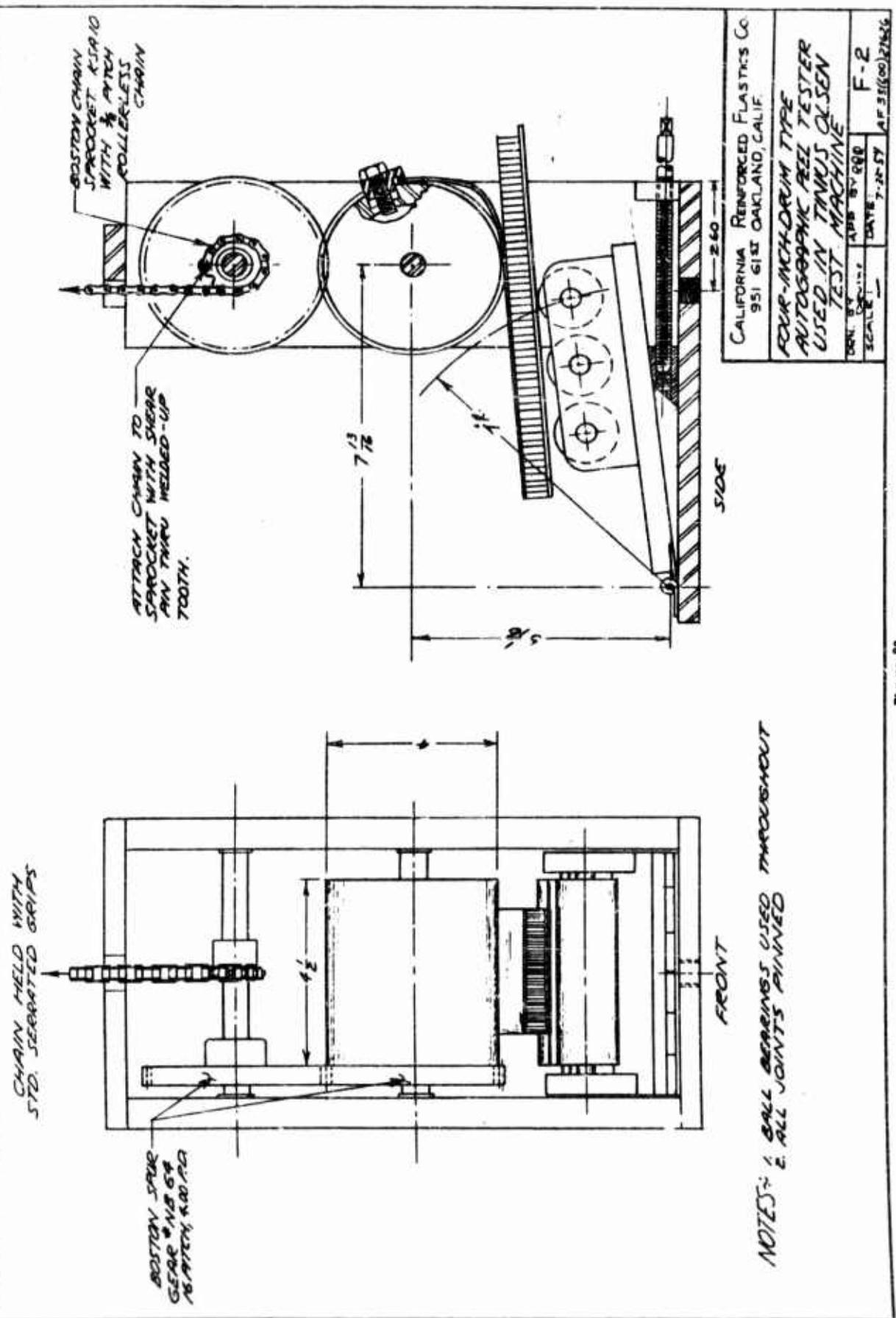
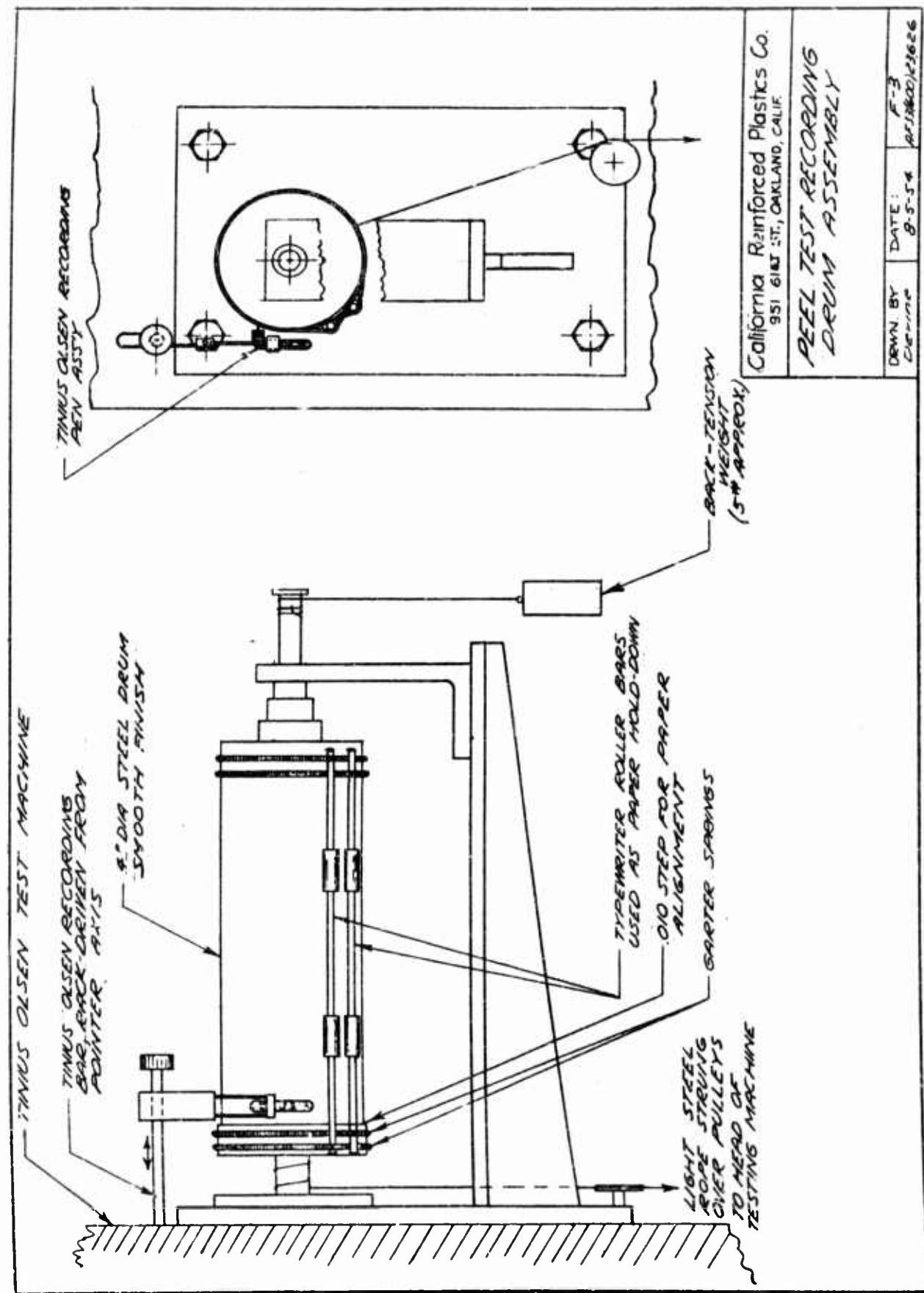
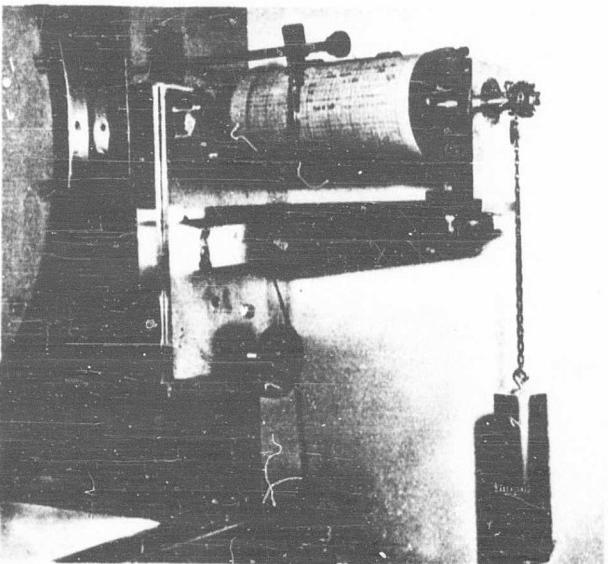
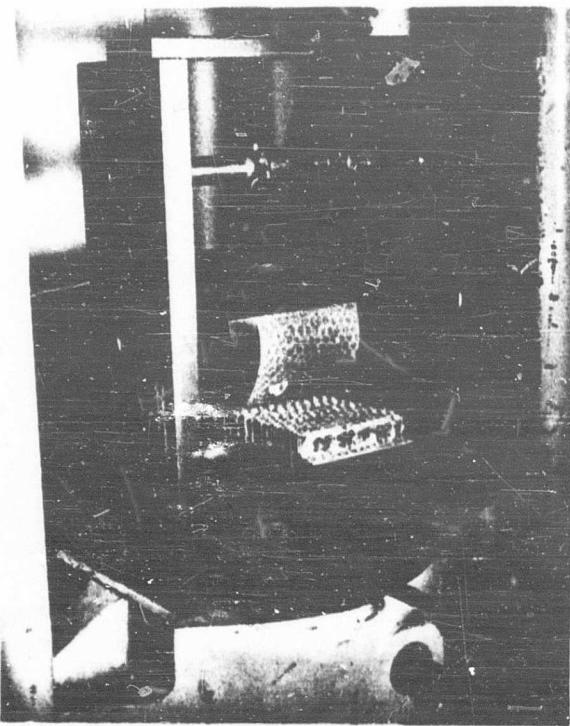


Figure 82





Figures 84 & 85: Autographic peel test apparatus in Tinius-Olsen test machine. (Special recording drum at right uses standard Tinius-Olsen pen and indicating bar)

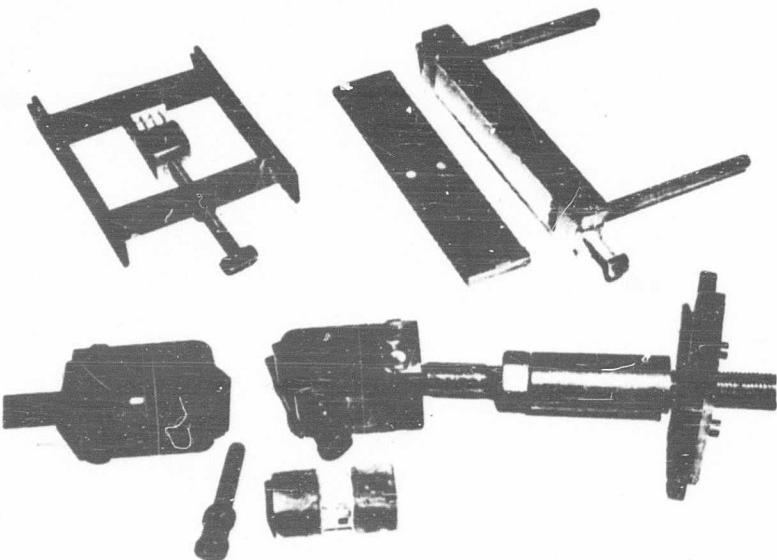


Figure 86: Flatwise tensile test apparatus. Upper left: Curing fixture for "422" bonded blocks. Upper right: Block-sanding fixture with height control platform. Bottom: Modified Forest Products Laboratory flatwise tensile grips (lower grip is at right, with centering plug in place)

## APPENDIX III

### PLANT LAYOUTS

Drawings "PL-1" and "PL-2" included at the end of this appendix show proposed plant layouts for the manufacture of flat aluminum honeycomb sandwich composite.

#### Drawing PL-1 (Figure 8)

The design represents a complete plant, manufacturing a high volume of flat material of the order of 5000 square feet per shift. The proposed continuous-coil processing line and semi-continuous core-priming and drying lines, designed in this project have been incorporated here.

The basic assumptions used in developing layout PL-1 were as follows:

1. A continuous-coil processing line would be included in the plant space. (It may, in fact, be more realistic to assume that the line would be operated in a separate facility by a firm supplying processed coil to the entire sandwich industry.)
2. The plant would purchase raw materials in the form of finished (sawed) honeycomb, coiled and sheeted aluminum, liquid adhesive, supported-film adhesive, wood strip, and extrusion stock.

(Note: In order to assure that the core material is not subjected to deterioration from storage it might be technically more desirable to procure it in a primed condition from the suppliers.)
3. The major portion of the plant's activity would be directed toward the fabrication of flat panels having few complicated details, other than heavy-density (wood or metal) edging reinforcements. The majority of facings in these panels would be under 0.040 inches in thickness, allowing utilisation of continuous-coil processing techniques.
4. The continuous processing units would have to be augmented with batch operations in order to process edgings and details, and to handle heavy-gage facings which could not be processed continuously.

Appendix III, Continued

5. A limited amount of extra space in the batch-processing areas could be devoted to the processing of contoured or special assemblies.
6. The "shift" capacity of the continuous-coil and core-priming lines would exceed that of the layup, bonding, and finishing departments. The following approximate square footage rates per shift (in terms of panel square footage) would apply:

Coil Line (assuming 0.016 material, 36 " wide 12 ft./min.)	8,000 sq.ft./shift
Core Line (assuming 4 passes)	10,000 sq.ft./shift
Presses (assuming 5 presses x 5 openings):	5,000 sq.ft./shift
Layup Line:	(Dependent on com- plexity of part)
Finishing Line:	(Dependent on com- plexity of part)

The panel area assumed here is approximately 30 square feet. If a very large demand for panels without edgings or detail parts existed, layup time would impose no limitation, and if additional presses were procured, the capacity could be extended to approximately 9,000 square feet of panel per shift, for as many as 18 shifts per week. Where relatively complex flat panels were in the majority, the layup and finishing departments might have to work three shifts per day, while the continuous-processing lines would be utilized less than five shifts per week. In this case, the savings to be realized from continuous processing would be reduced but would probably still be significant. Both lines would still provide outstanding technical advantages, and it is probable that excess capacity could be utilized in processing materials for other firms. (The continuous-coil line could be modified to perform other chemical processes and to apply other types of coatings to aluminum for both military and commercial applications.)

APPENDIX III, Continued

The following specific features incorporated in "PL-1" are called to the reader's attention:

1. The flow of materials used in the high-production panels takes a "U"-shaped flow pattern through the plant. It would be equally (or more) desirable to orient all the flows in straight lines, parallel to the continuous-coil line, provided that the configuration of the building and the location of the transportation docks permitted.
2. "Low production" and "batch process" areas have been set aside from the areas in which materials pass in volume.
3. The aqueous cleaning facilities have been isolated from other parts of the plant by partitions, to prevent water vapors and acid fumes from reaching the areas in which adhesive is handled or aluminum is stored.
4. Wherever possible, areas where adhesives or solvents are handled have been consolidated and isolated by fire walls.
5. Core materials are stored on flats, resting lengthwise on tiers of shelves. There is no fixed line of demarcation between primed and unprimed core storage areas.
6. Panel layup is performed on a "skate-wheel" conveyor line, using the cauls as surfaces. In operation, it is proposed that two cauls are first placed end-to-end on the conveyor. Press pads and facings are then placed on the cauls. The assembled core (with tapes, edgings, inserts, etc.) is then placed on one of the facings, and the other facing, caul and pad are folded over to make the finished press load. (It may be desirable to warm the materials first and apply some pressure to insure that the components will not be shifted during subsequent handling.)
7. Although the presses shown in the layout are "side-loading", "end-loading" presses are equally acceptable.

Drawing PL-2 (Figure 88)

A partial plant layout of a line for cleaning, priming, and drying cut sheets is shown at the end of this section. Essentially, it represents an extrapolation of existing batch-processing techniques to achieve higher production at lower costs. This layout is not a firm design and would be subject to refinement by specialists in automatic conveying systems.

The capacity and square-footage cost saving which could be realized from such a system are not equivalent to those offered by a continuous - coil system. Since the availability of heat-

Appendix III, Continued

treated coils may be delayed for some time, it is felt advisable to present an "interim" or "alternate" process layout. The "continuous monorail" shown in this drawing is the only major departure from existing techniques. (The conveyorized spray-priming system has already found successful application in sandwich manufacturing.)

It is proposed that the continuous monorail system include four hoists, controlled by two men. The operators would actuate an alarm timer at each tank as the rack was immersed; the timer at each tank would be pre-set at a fixed interval according to the following tentative schedule:

Hot alkaline tank:	10 minutes
Hot rinse tank:	2 minutes
Hot acid tank:	10 minutes
Cold rinse tank:	1 minute
Warm air dry: (2 timers)	20 minutes

The long drying time in this cycle suggests that the warm-air drying oven should be large enough to hold two racks at one time. Allowing for some transfer time between tanks, the total immersion cycle would be 50 minutes per rack. A new rack could be started every 15 minutes. (approximately), allowing a maximum of 4 hoists in the process tanks at one time. One hoist would be out of the cycle for 10 minutes out of every 15, for unloading and loading. Assuming 4 ft. x 8 ft. sheets, six to a rack, and that maximum utilisation is not attained, the production capacity of this system would be approximately 5,000 square feet (2500 square feet of sandwich) per shift. This figure would satisfy only half of the nominal capacity (5,000 square feet of sandwich per shift) of the plant shown in Drawing PL-1.

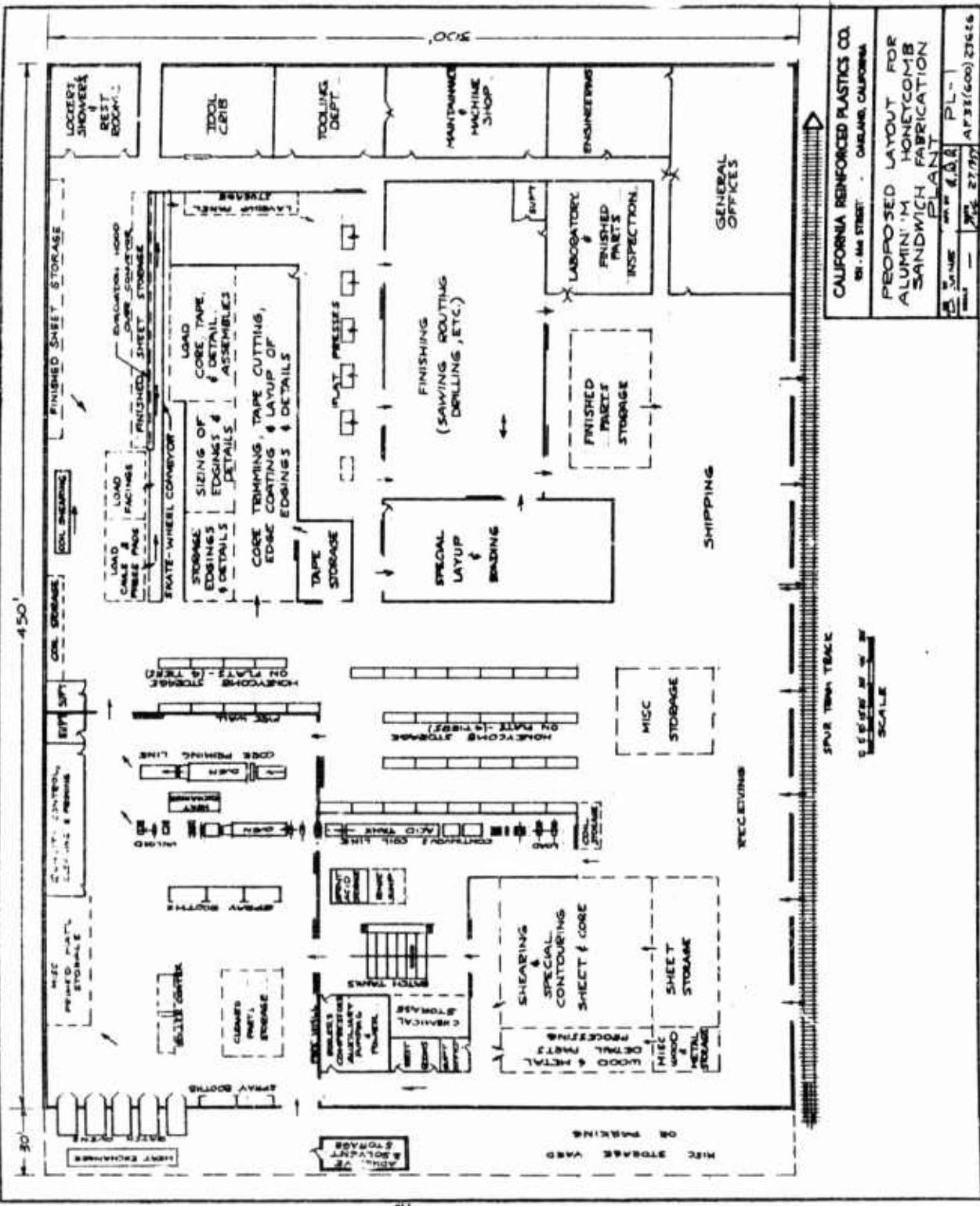
It should be noted that savings realized by buying in the coil form (when wide, light-gage coils of heat-treated aluminum become available) can be applied to batch processes as well as to continuous web process, since purchased coils can be readily converted into sheets.

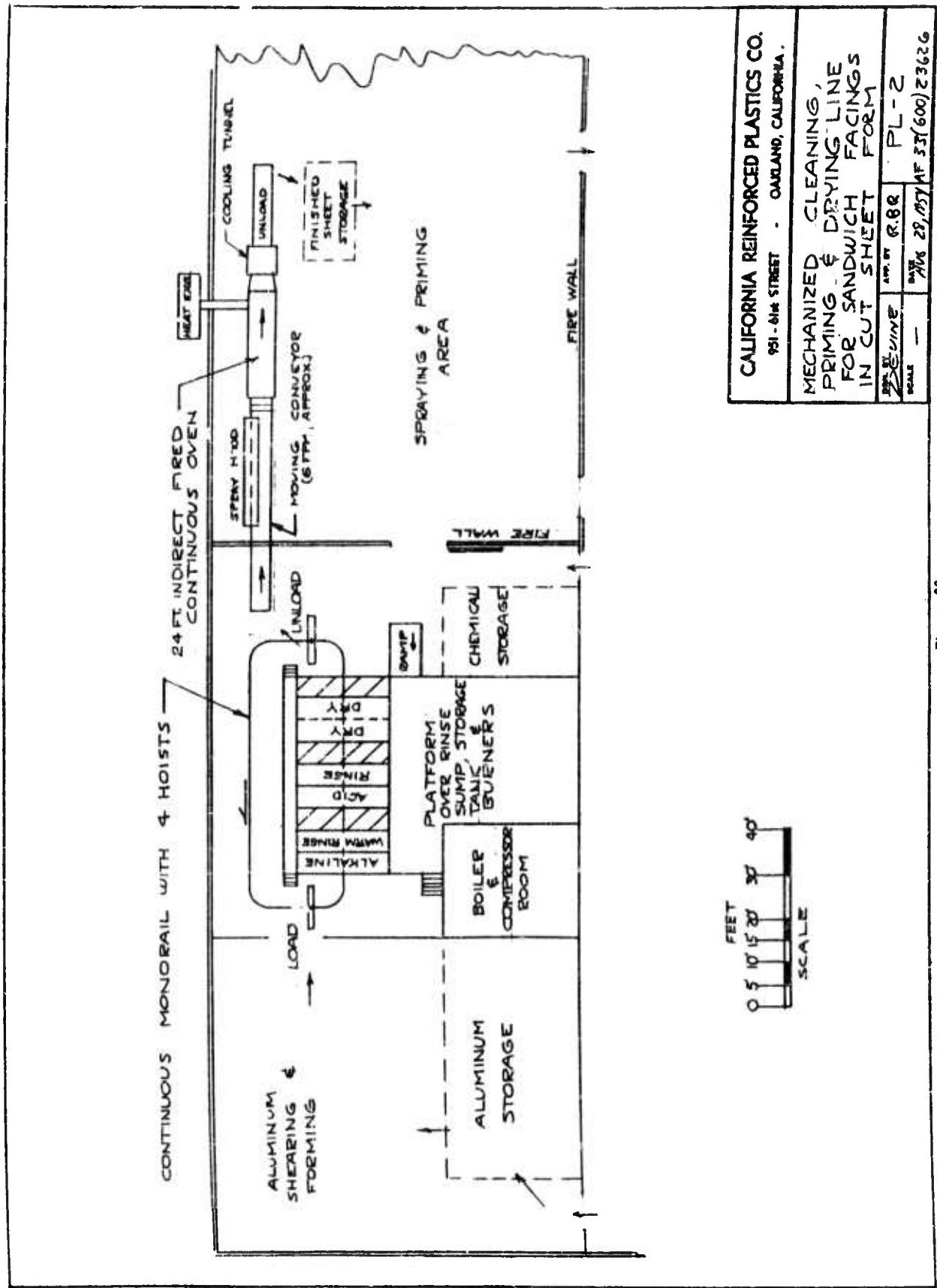
The following features of the "batch system" layout are worthy of note:

1. The conveying medium for aluminum sheets after shearing would be the cleaning racks. The racks would be transported to and from the monorail loading station on carts. An empty cart would receive the empty rack and a loaded rack would be wheeled in place and coupled to the hoist. The sheets would not leave the racks until unloaded at the infeed end of the priming conveyor.

Appendix III, Continued

2. The operators at the infeed end of the conveyor would wear clean gloves and would perform no other task than transferring the clean sheets from the racks to the conveyor.
3. The conveying system through the spray booth and oven would run at a speed of approximately 6 feet per minute. A continuously moving web of Kraft paper would be used to cover the surface of the conveyor, protecting the conveyor and the backs of the sheets from the spray.
4. The continuous oven (indirectly fired) would be of the same general type as proposed in the continuous-coil and continuous-core lines.





## APPENDIX IV

September 30, 1954

### SUPPLEMENT TO PROPOSED SPECIFICATION S-4, CONTINUOUS-COIL CLEANING AND PRIMING LINE

Prepared by Hexcel Products Co., a division of  
California Reinforced Plastics Co.  
under Contract No. AF 33(600)-23626  
(This is not a Government specification)

IMPORTANT: The information contained in this supplement supersedes that in "Proposed Specification S-4", where applicable. The specification, itself, was prepared during the performance of the contract and was distributed widely among manufacturers of strip-processing equipment for comment and criticism. A number of important revisions were suggested by the manufacturers. Because these firms have become familiar with the original specification and have retained it in their files, it has been republished in substantially unchanged form in the final report of Contract No. AF 33(600)-23626. The important revisions have been published separately in this supplement. A number of minor typographical corrections and improvements in clarity have been made in the specification, but changes of this type have not been shown in the supplement.

The revisions contained in this supplement follow the outline of "Proposed Specification S-4". Each revision has been given a circled number which is also shown in the margin of the latest printing of the specification contained in the Final Report.

#### I - INTRODUCTION

(No important corrections)

#### II - PROCESS REQUIREMENTS

##### C - "Process"

- ① Paragraph 3: (Tabulation of acid immersion times): Change: Times on 0.032 and 0.040 inch-thick material from 6 minutes to 4 minutes and 5 minutes, respectively. (Additional data have indicated that the shorter times are adequate.)
- ② Paragraph 8: Change sentence: "The web should be subjected to an approximately uniform temperature gradient, starting at 100°F and ending at 300°F, for a minimum period of 1.2 minutes." to the following: ".....to an approximately uniform oven-temperature gradient, starting at 100°F and ending at 350°F..."
- ③ Paragraph 9: Revise second sentence to read: "A protective web of nonreactive material such as polyethylene is to be introduced into the coil as an interleaf when coating both sides of the strip with adhesive, otherwise no interleaf need be added." Revise third sentence to read: "The finished coils will be removed and stored in a cool, clean, dry place..."

Appendix IV, Continued

Supplement to Proposed Specification S-4, Continued

III - EQUIPMENT REQUIREMENTS

D - Spray Washer (page 7)

- (4) Delete sentence in last paragraph: "It should not be recirculated" and substitute: "It may be recirculated".
- (5) Delete portion of last sentence in parenthesis: "...(made up of two 6-inch dia. slit rubber rolls)..." and add the following to the end of the paragraph: (Slit rubber rolls may leave wet streaks on the strip.)

H - Oven (page 14)

- (6) First paragraph: Underline the entire first sentence, and change: "...Drawing C-3 ..." to: "...Drawing L-4..."

1. Assumptions (pages 14 to 16)

- (7) General Note: Experienced oven designers have pointed out that a considerable error was introduced in the calculations by neglecting the heat capacity of the aluminum and heat of vaporisation of the solvents.

They have further pointed out that the strip temperature will never approach the surrounding temperature in the oven and that the temperature differential produced here is likely to cause condensation of water vapor (a product of combustion) onto the material. The undesirability of this condensation makes it necessary that an indirect-fired heat exchanger be substituted for a direct-fired unit, to prevent the products of combustion from entering the oven chamber. This indirect-fired unit may be either gas-fired or oil-fired. An efficiency of the order of 70% may be expected from an indirect-fired unit. (The computations indicated only the estimated output of the heat exchanger in BTU/hr.)

In view of the fact that the temperature of the strip may be as much as 50°F below the temperature of the surrounding air, the nominal oven temperature at the third stage should be changed from 300°F to 350°F, to assure that the web reaches 300°F. The temperature of the air leaving the heat exchanger would, correspondingly, have to be raised to 400°F (approx.). Taking three new factors into consideration (increased speed on heavier material, heat of solvent vaporization, and increased operating temperature), the estimated output from the heat exchanger would be revised from 620,000 BTU/hr. to approximately 750,000 BTU/hr. (This figure is still very low compared

Appendix IV, Continued  
Supplement to Proposed Specification S-4, Continued

with some outside estimates.) In sizing a heat exchanger of this type it is advisable to provide a generous amount of extra capacity.

Assumption "a" (page 15)

- (8) Revise temperatures at "HEAT EXCHANGER" and at "H" in sketch from 350°F and 300°F to 400°F and 350°F. Change  $W_d$  on middle damper to  $W_b$ .

Assumption "h" (page 16)

- (9) Change 300°F to 350°F.

Assumption "i" (page 16)

- (10) Revise to specify "indirect-fired heat exchanger".

4. Calculations

(11) (d) Heat Input (page 17)

Delete existing numerical heat input rates and substitute "750,000 BTU/hr. approximately."

(12) (e) Air Weight Rates (pages 17 & 18)

All weight rates calculated here are subject to error, due to revised temperature assumptions, recognition of the heating of the aluminum web, etc. The magnitudes of most of these figures remain substantially the same, however.

IV - TABULATION OF INDIVIDUAL COMPONENTS

- (13) Page 20: Revise: "Post-alkaline spray rinse unit" to read: "Heated postalkaline spray rinse unit with recirculation."
- (14) Page 21: Insert: "1 - Air cooling stage" between: "Four-stage evacuated oven..." and "Four-roll drive bridle."
- (15) Page 21: Change: "6-inch dia. rubber-covered 'LCRIG-ALIGNER' slit full cylindrical (squeegees)" to read: "Squeegee rolls".
- (16) Page 21: Insert: "2 narrow-bodied stoneware, 16-inch-dia. (with bearings and mounts)" between "Full cylindrical stoneware ..." and "Water-cooled, hard-chrome plated ..."

Appendix IV, Continued  
Supplement to Proposed Specification S-4, Continued

DRAWINGS:

L-4

- (17) Delete note under Oven, and substitute: "2100 CFM (AT 70°F) HEATED TO 400°F IN 750,000 BTU/HR. (APPROX) INDIRECT-FIRED HEATER."

- (18) Change temperature shown in last oven stage from 300°F to 350°F.

L-4 and L-5

- (19) Add leaders to interleaving spools and "4-INCH-DIA. EXPANDING ROLLS", with the following note: "USED ONLY WHEN COATING BOTH SIDES OF STRIP".

L-5

- (20) On the four small-diameter (6-inch) rolls designated as "B" (slit cylindrical rubber), the "B" designation should be crossed out and the word "SQUEEGEES" substituted.

APPENDIX IV, Continued

PROPOSED SPECIFICATION "S-4" FOR CONTINUOUS-COIL CLEANING AND PRIMING LINE\*

Prepared by Hexcel Products Co., a division of  
California Reinforced Plastics Co.  
under Contract No. AF 33(600)-23626  
(This is not a Government specification)

I - INTRODUCTION

This specification is to be used in conjunction with drawings L-4, L-5, and L-6. It supersedes "Tentative Specification S-3" and Drawing L-3. Applicable drawings referenced herein are included at the end of this specification.

The intent in preparing this specification is to provide potential builders and users of the equipment with a useful guide which will permit them to go into production in the shortest time, with a minimum of development effort. The specification is not intended to be rigid or binding, but is offered as one set of practical conditions which appear to be optimum. The contractor and the Air Force cannot assume responsibility for the mechanical performance of the line or for safety hazards involved in its operation.

The purpose of the proposed line is to apply a protective prime coating of resinous adhesive to one or both sides of continuous webs of heat-treated clad aluminum, after first preparing the surfaces of the metal for adhesive bonding. The primary use for the finished material will be as "facings" in aluminum honeycomb-sandwich composite. Nominal output of the unit is to be approximately 3000 square feet per hour.

The process and the equipment recommended here are intended to supplant existing batch techniques, which are not optimum from the standpoints of cost, capacity, and consistency of quality.

The following outline is presented for the convenience of the users of Proposed Specification S-4 :

- I - Introduction
- II - Process Requirements
  - A. Material processed
  - B. Speed range
  - C. Process
- III - Equipment Requirements
  - A. Rolls and Tracking Devices
  - B. Brakes and Drives
  - C. Splicer and Accumulator
  - D. Spray Washer and Rinse

\* This specification has been partially superceded by a supplement. Circled numbers and arrows have been placed in the right-hand margins to indicate where important changes have been made.

Appendix IV, Continued

- E. Acid Dip
  - F. Post-Acid Rinse, Drying, and Cooling
  - G. Coaters
  - H. Oven
  - J. Shearing and Stacking Line (Separate Accessory)
- IV - Tabulation of Individual Components, with estimated costs.
- V - Drawings: L-4, L-5, L-6

II - Process Requirements

A. Material Processed

Aluminum coil, 18 to 48 inches wide, 0.008 to 0.040 inches thick. Maximum weight of coils: 5000 lbs. Oiled finish. No stenciled letters. Arbor dia.: 16 inches.

B. Speed Range

5 to 20 Lineal FPM (Note: This range was quoted as "10 to 35 FPM" in the earlier draft of this specification.)

C. Process

1. Remove oil and other foreign matter to give water-break-free surface in two-stage inhibited, commercial alkaline spray cleaner at 170° F, approximately. Solution must not dry on surface before rinsing.
2. Spray-rinse at 130° to 140° F. Remove excess rinse by squeegee.
3. Dip in hot (155° to 165° F) solution of 25% sulfuric acid and sodium dichromate, contained in ceramic materials. The following tentative immersion times apply for various thickness of Alclad 24S-T3 material:

Thickness (Inches)	Time (Minutes)
0.008	1-3/4
0.012	2
0.016	3
0.032	6
0.040	6



(Note: Commercial "room-temperature" spot-welding solutions are no longer offered as an alternate.)

4. Rinse in two spray stages; first stage to be a cool, recirculated solution containing acid carry-over, second to be hot (130° to 140° F) fresh water. Remove excess rinse by squeegee.

(2)

Appendix IV, Continued

5. Dry thoroughly in warm air (not to exceed 150°F).
6. Cool to 85°F (maximum).
7. Coat one or both sides (normally one side) of the web completely and uniformly with dilute resinous adhesive, applied at a solids content of the order of 7 to 12 pct. Weight of dried, cured solids to be 0.001 to 0.003 lbs/sq. ft.
8. Immediately after the wet coating is applied, forced drying at a moderately elevated temperature is to begin. The web should be subjected to an approximately uniform temperature gradient, starting at 100°F and ending at 300°F, for a minimum period of 1.2 minutes, during which time the solvents will be removed and the resins will receive a partial cure. Care must be taken to prevent the wet, cool coating from absorbing atmospheric water vapor in the interim between coating and entry into the oven. The web must not be allowed to come in contact with any rolls, walls, or partitions from the instant of coating to such a time as it has been dried, cured, and air-cooled to a temperature of 120°F, approximately. Before coming in contact with any rolls which are driven, it should be cooled to a maximum temperature of 90°F. Water-cooled rolls may be used to bring about the reduction from 120°F to 90°F. ←(2)
9. The finished coated web is to be rewound into coils, at a relatively low tension. A protective web of nonreactive material such as polyethylene is to be introduced into the coil as an interleaf. The finished coils will be removed and stored in a clean, dry place until such a time as they are cut into sheets of desired size. The initial cutting operation will be combined with a "breaking" operation, which will give the sheets a reasonable degree of flatness. ←(3)

III - EQUIPMENT REQUIREMENTS

A. Rolls and Tracking Devices

A minimum diameter of 12 inches will be maintained where the web is to be wrapped about any roll while under tension. A web of alclad 24S-T4 material (minimum yield strength = 42,000 PSI; modulus =  $10.6 \times (10)^6$ ) which is 0.040 inches thick will not be stressed above its elastic limit on a 12-inch-diameter roll. The

(3)

Appendix IV, Continued

calculations are shown as follows:

Stress in outer fibers:

$$S = E \frac{x \text{ web thickness}}{\text{aluminum roll diameter}}$$

$$= 10.6 (10)^6 \times \frac{0.040}{12}$$

$$= 35,000 \text{ PSI}$$

In actuality, clad sheets have been found to show some permanent bending under conditions which should not exceed the elastic limit of the outer fibers. This contradiction may be explained by the fact that the outer fibers are composed of "cladding" alloys, which are soft, ductile, and low in yield strength. In the opinion of the contractor, successive permanent deformations in the outer cladding alone do not bring about a "work hardening" of the sheet as a whole, and can be overlooked as a criterion in the selection of minimum roll diameters.

Installations which are mechanically comparable to the one proposed herein are able to process 0.051-inch-thick webs of "non-heat-treatable" aluminum without difficulty. These materials have substantially the same modulus but are much lower in yield strength. Evidently, some work hardening of the material is tolerated in these processes, but it is believed that the aircraft industry would not generally favor work hardening on heat-treated alloys.

The design of the system must avoid conditions which would cause scratching of the web, to conform with most existing aircraft specifications.

It is assumed that the coiled aluminum received for processing will contain camber, flatness irregularities, short edge fibers, and other defects common to coiled (and particularly heat-treated) strip.

Although the low lineal speed should favor good tracking, it is assumed that special automatic means must be provided to keep the web centered. Furthermore, it is mandatory that relatively low tensions be utilized. The "LORIG-ALIGNER" system (patented by U.S.Steel, Pittsburgh, Pa.) is the only currently available system known to the contractor that will fulfill these requirements. The drawings attached to this specification have incorporated the "LORIG-ALIGNER" system, with the general approval of U. S. Steel. Although the roll layouts are believed to be

(4)

#### Appendix IV, Continued

substantially correct, the builder should review the design carefully with U. S. Steel before purchasing and installing any part of the line. The use of rolls designated as "automatic self-centering" and "slit, rubber covered", as well as the use of the accumulator configuration, is subject to royalty fees. (Ordinary full-cylindrical rolls and narrow-bodied rolls are not patented.)

It should be noted that two of the stoneware rolls have a narrow-bodied configuration, to reduce tracking error.

In the event that the finished coils are found to be poorly wound, as a result of "camber" error, it may be advisable to add "ASKANIA" tracking systems later to the two rewind stands. The "ASKANIA" system is a lateral correction device, activated by two air jets which sense lateral movement of the edges of the web. Since the degree of camber error in wide, heat-treated coiled aluminum cannot be evaluated at this time, it is not known whether such a system is needed.

In order to introduce the protective interleaf without wrinkling, it is recommended that it be passed over an "expanding" roll of the type manufactured by the Mount Hope Machinery Company.

#### B. Brakes and Drives

Available information indicates that the horsepower required to drive a web through a process of this type is proportional to speed and brake tension only; bearing friction and bending of the web are negligible factors.

Referring to drawing No. L-4, a tension of 50 lbs. has been introduced to hold the web flush against the accumulator rolls. It is necessary to keep this figure low to make it equal (nominally) the amount of tension induced by the dead weight of the accumulator when it is in operation.

The additional tension applied between the accumulator and the spray washer must bring the total tension up to a value which will prevent excessive sag in the long catenaries through the acid tank and oven. Assuming that the catenaries are parabolas, that one lineal foot of 48-inch-wide aluminum, 0.040 inches thick weighs 2.32 lbs. in air, and that a maximum sag of fifteen inches is allowed in the oven, maximum tension is calculated in the following manner:

(5)

Appendix IV, Continued

$$\text{Tension} = \frac{(\text{length})^2 \times (\text{wt. per lineal ft.})}{(8) (\text{sag})}$$

Unsupported length in oven and cooling tunnels: 38 ft.

$$\begin{aligned} T_{\text{oven}} &= \frac{38^2 (2.32)}{8 (1.25)} \\ &= 334 \text{ lbs.} \end{aligned}$$

This tension would give the following sag in the acid tank (assuming that fluid is water and that web weighs only 1.46 lbs. per lineal foot in this medium):

$$334 = \frac{(35)^2 (1.46)}{(8) (\text{sag})}$$

$$\text{sag} = 0.60 \text{ ft.}$$

Since the sag in the acid tank will be relatively small, the oven is the ruling catenary. Maximum tension should be approximately 350 lbs., of which 50 lbs. is supplied as a fixed amount, ahead of the accumulator.

All of the driving torque is applied in one unit, a four-roll bridle. The maximum design horsepower required here is determined as follows:

$$\begin{aligned} \text{Power} &= \frac{\text{tension} \times \text{speed}}{33,000} \\ &= \frac{350 \text{ lbs.} \times 20 \frac{\text{ft}}{\text{min}}}{33,000 \frac{\text{ft-lb}}{\text{min}}} \text{ H.P.} \\ &= 0.2 \text{ H.P.} \end{aligned}$$

A one-horsepower motor, in combination with a variable-speed drive and a speed reducer, is recommended for driving the bridle.

The tension applied by the rewind drives should be low and should be transmitted through adjustable clutches.

C - Splicer and Accumulator:

The accumulating device is of the "dead-weight" type. The total weight of the rolls and carriage should be four times the 50 lb. tension, or 200 lbs. A mechanical pull-down device should be included to positively reposition the carriage after the splice has been made.

(6)

Appendix IV, Continued

It is recommended that the splicing be accomplished by two stitchers, having throat depths of approximately 25 inches. These should be mounted opposed, across the centerline of the web, on rack-driven carriages. In operation, the stitchers would make two rows of stitches across the splice, at four-inch intervals. The first pass would be made inward, from the edges to the center; the second pass would begin at the center and move outward to the edges. The movement of the stitcher carriages would be intermittent, allowing a short dwell for each stitch. The stitching wire should be of #18 (0.0475-inch dia.) stainless steel, at a tensile strength of 230,000 PSI. A relatively flat "clinch" should be given to each stitch.

While the stitchers were in action the two overlapped ends of the web would be positioned and held by clamped pressure from the two pairs of rubber-covered "nip" rolls, which would normally be free-turning, and spaced apart. As the trailing edge of the web was stopped in position for splicing by the clamping action of the outfeed rolls, the gravity-loaded accumulator carriage would begin to rise. The operator(s) would then feed the leading edge of the new web through first set of rolls, lap it over the trailing edge of the first coil, clamp the two infeed rolls, and actuate the dual stitchers for their first pass. At the end of the first pass, the front set of clamp rolls would be loosened and the rear set would be allowed to roll so that the splice would move about one inch with respect to the splicing heads. On completion of the second stitching pass, the remaining set of clamped rolls would be released and the accumulator pull-down mechanism would be actuated.

D - Spray Washer

The spray washer shown in drawing L-4 is a more or less standard straight-pass unit, used for applying hot, inhibited, non-foaming alkaline cleaners at high velocities. The pressure capacity, number of spray heads, etc. should be adjustable. The unit should be built with two sumps having independent suction lines, so that the solution can be replaced without stopping the process. Since it is expected that the solution will have a relatively short life on oiled material, the sumps should have a generous capacity.

The material should not be allowed to dry on the web surface between the alkaline wash and rinse. The post-alkaline spray rinse should be hot (130-140°F) and variable in amount. It should not be recirculated. A squeegee(made up of two 6-inch-dia. slit rubber rolls) should be provided to prevent alkaline "drag-out" from reaching the acid solution.

E - Acid Dip

The acid solution should be maintained at an average temperature between 155 and 165°F., with the least possible amount

Appendix IV, Continued

of temperature gradient throughout the tank.

A careful selection of materials must be made in the design of the tank and its associated fittings and accessories. The solution in question is composed of a strong acid and a strong oxidizing agent at elevated temperature. Surveys of the industry have indicated that batch tanks of stainless and plastic-lined tanks have not held up well, while ceramic constructions have appeared to be adequate. The following is an itemized listing of a number of possible tank, trim, and accessory materials, with comments:

Ferrous metals:

The corrosion resistance of the ferrous metals (with the known exception of "CARPENTERS STAINLESS NO.20Cb") is improved by the presence of sodium dichromate. Stainless steels which are exposed to temperature, however, are subject to attack, particularly at welds, and are not suitable as a tank material. Ferric ion in solution is believed to be a contaminant detrimental to the process and the use of ferrous metals as trim should be avoided where possible. Exceptions would be where a stainless steel pumping system is used to drain an expended solution, where an expended solution might be stored (cold) before dumping, and where a cold rinse containing drag-out would be circulated. In no case should ordinary carbon steels be used, hot or cold.

Organic Materials:

Most plastics (including polyvinyl chloride) are subject to oxidation attack by the dichromate, at the temperatures in question. Polyvinyl chloride is believed to be acceptable for use as a membrane where temperatures do not exceed 120°F, and as a hooding material, where temperatures and concentrations are reduced. "TEFLON" shows no apparent ill effects from immersion in the solution. Polyethylene has not been evaluated. All applications of organics (including those where plastics may serve as a binder for compressed carbon) should be reviewed with caution.

Ceramics and Stoneware:

These materials are believed to be entirely dependable. It is possible that some types of fillers or mortars used with acid-proof brick are susceptible to oxidation.

Lead:

The presence of lead in the tank may be detrimental to the process. (Ceramic is believed to be a more suitable tank

Appendix IV, Continued

material than lead for various other reasons.)

Aluminum:

Low-alloy aluminum (28, 38, etc.) is subject to slow attack, but has a distinct advantage in that it introduces no directly harmful contaminants. It is desirable as a material for "trim" pieces, provided that frequent replacement can be tolerated. Alloyed aluminums are not suitable.

Glass and Pyrex:

Believed to be entirely suitable for immersion.

Monel:

Unsuitable.

Copper Alloys:

Not evaluated.

The buyer should assure himself that the supplier is aware of both the acidic and the oxidizing characteristics of the solution, at the temperatures in question. Where any doubt as to acid resistance or oxidation resistance exists, the supplier should test his materials in the laboratory. A solution of one part sodium dichromate, ten parts concentrated sulfuric acid, and thirty parts water may be used as a test medium. The temperature and other conditions of the test should be chosen to simulate actual conditions.

Steam is believed to be the best medium for heating the acid solution. As far as is known, there is no objection to the direct introduction of the steam through nozzles. Pressed carbon is preferred to ferrous materials for submerged heat-exchanger parts, from the standpoint of solution contamination.

It is not known whether steam will be available at the eventual location of the unit. For this reason, a 15 H.P. steam generator is included in the tabulation of individual components required for the line.

The only other known means of heating this solution in a ceramic tank is by electricity, with Pyrex immersion heaters.

The acid tank must be provided with a temperature control and a recording device. (Optimum web speed for a given gage is a function of acid temperature.)

Appendix IV, Continued

The tank proposed here is relatively long and some attention must be given to thermal expansion. There are a number of methods of compensating for expansion, and no one method is being specified here.

In order to protect workmen and surrounding equipment from the acid fumes, the tank should be thoroughly covered, and evacuated to a degree which will provide a slight negative pressure at the openings. Portions of the hood must be easily removable to allow access to the web. It is believed that polyvinyl chloride is a satisfactory material for use in the hooding and ventilating equipment.

The contractor has not experimented with stoneware rolls, but it is known that they have been used successfully in the strip-pickling of steel. The rolls proposed here are relatively large in diameter, and are mounted on an axis above the top of the tank, to allow the bearings to be isolated from the acid atmosphere.

The disposal of deteriorated acid solutions represents a problem which must be anticipated by both the equipment suppliers and users. The method chosen for disposition would depend on the locality. In the opinion of the contractor, a separate storage vessel for old solutions would be desirable. Here, the acid could be cooled to a temperature low enough to permit it to be hauled away, or it could be neutralized and dumped in a sewer. The vessel should have a capacity somewhat greater than that of the main tank, and may be of stainless steel construction. A corrosion-resistant pumping system should be provided to transfer the deteriorated solution from the main tank to the storage tank. The suction line for this system would be removed from the active solution in the main tank under normal operating conditions.

F .. Post Acid Rinse and Drying:

The post-acid rinse has been shown in two stages. The first rinse is recirculated cold with the "drag-out" contained in the water. No experimental data are available to support the use of a recirculated acid rinse, but it is considered desirable on other comparable processes. A final warm rinse is not optimum for obtaining good adhesion, but is included as a concession to ease of drying. The temperature of the warm spray should be no higher than that needed to assure good drying. In no case should it exceed 140°F. The vapors from the rinses should be vented off, and stainless steel or other corrosion-resistant materials should be used throughout.

Local ordinances may require that acidic rinse waters be neutralized before dumping. This is sometimes accomplished in automatic systems, in which given amounts of caustic soda are

#### Appendix IV, Continued

dumped into the rinse in a sump. A recording controller senses the neutrality and maintains a record of the actual pH of the waste passing into the sewer, for inspection by city officials.

A vertical, counter-flow, gas-fired heater is used to dry the web after the last rinse. After passing over the two narrow-bodied steel rolls at the top, the web is air cooled, prior to coating. It is absolutely essential that the web be dry as it reaches the coater(s).

#### G - Coaters

The system should be capable of coating either the bottom side alone, or both sides. Normally only the bottom side is coated, and the top side must be kept absolutely clean and free from adhesive.

Research conducted by the contractor has indicated that there is no "one-side-only" coating system which would be capable of handling all thicknesses from 0.008 to 0.040 inches. It has been concluded that two types of coaters are required. These coaters are shown in some detail in drawing No. L-6, at the end of this specification.

Most systems for coating one side utilize some type of dry back-up roll. In experiments with the adhesive in question, the contractor has never been able to keep back-up rolls from becoming wet, when coating webs thinner than about 0.020 inches. Excellent coatings have been applied to webs as thin as 0.006 inches however, from a "reverse-roll" system having no back-up roll. Here, the web, under tension, takes a slight bend about the applicator roll to maintain even contact. It is doubtful that this system would be dependable on heavy gages unless extremely high tensions were used to smooth out flatness errors from heat treating and/or rolling.

Since the reverse coating roll is not to be used on the heavier gages (0.025 inches upward, approximately), the roll diameter has been shown as 8 inches. This roll may be of steel, hard-chrome plated. Both it, and the hard-chrome-plated doctor roll, should be ground smooth and true. The doctoring gap between the two rolls should be adjustable from 0.002 to 0.010 inches by a calibrated mechanism. The rolls and pan should be enclosed, except for a portion of the applicator roll, which will protrude. The entire enclosed unit should be mounted on an adjustable elevating mechanism, which could be lowered rapidly to permit splices to be passed. (Splices carry entrapped liquids from the aqueous cleaning operations which would otherwise contaminate the adhesive.)

Appendix IV, Continued

The reverse-roll coater should be driven through a variable-speed mechanism. (The optimum peripheral speed of the roll in the reverse direction is nominally equal to the forward web speed.) The electrical equipment must be explosion-proof. The doctor and applicator rolls should be geared together to run at the same peripheral speed.

The best configuration for coating either one or both sides of webs greater than 0.020 inches or 0.025 inches in thickness has appeared to be a plain set of doctored, smooth, resilient "squeeze rolls". This configuration is similar to that used in standard veneer coaters. Here, the metering of the adhesive onto the web is primarily a function of squeeze pressure. Although higher pressures give more consistent coatings, tracking may become a problem when very high pressures are used. Smoothly ground rolls give much better results than do grooved rolls with the adhesive in question. (Grooved rubber rolls are also undesirable because the grooving causes the roll surface to become very susceptible to solvent attack.)

The squeeze-roll coater should be made with a high degree of durability and precision, so that it may be counted upon to compete with the reverse-roll system on web thicknesses of the order of 0.016 or 0.020 inches. It will be found that solvent attack on the rolls of this machine will impair its ability to coat lighter gages, because of localized swelling. Experience has indicated that a neoprene of 70 Durometer will give a reasonable service life with the solvent system in question. (Other types of rubber may give better results, but neoprene is generally considered to be as good as any.) It should be possible to re-grind the rolls several times before re-covering them with new rubber.

The depth of rubber on the applicator rolls, as well as its hardness and degree of local swelling, will determine the lower limit of gage which can be successfully coated on one side. A shallower depth should reduce the lower limit on web thickness, but would also tend to make the coating less consistent at a given squeeze pressure. As a compromise, a depth of 3/8 inches is proposed.

The following details are recommended for the squeeze-roll machine:

1. Applicator rolls:  
Length: 52 inches  
Diameter: 8 inches (min.)  
Covered with 70 Durometer neoprene to a depth of 3/8 inches, ground smooth and true.

2. Doctor rolls:

Diameter: 7 inches (approx.)

Appendix IV, Continued

May be geared directly to applicator rolls or may run at reduced speed, through over-running clutch. Accurately calibrated adjusting screws to be provided for controlling doctor gap.

3. Babbitted seal plates to be furnished for top rolls.
4. Height of lower roll and pan assembly to be quickly adjustable, vertically, from one side of machine, so that web splices may be passed without danger of squeezing out entrapped liquid contaminants.
5. Top applicator roll to be provided with adjustable relief springs at either end, to prevent mechanical damage when splices are passed unattended. (Normal position of springs to be against a stop, with all resilient deflection taking place in the rubber roll coverings.)
6. Means should be provided for supplying torque to each set of rolls, individually, to substantially overcome frictional and tractive drag on the web. The magnitudes of these torques should be variable, but successful operation of the machine must not depend on synchronization of the coater drive speed with the web speed.
7. The coating machine, except for its electrical components, must be enclosed to prevent excessive solvent evaporation. Parts of the covering should be hinged and "blowout" panels must be provided to minimize explosion hazard.
8. All rolls should turn on ball bearings and should be mounted so as to be replaceable in a reasonably short time.
9. Adhesive circulating systems should be provided for maintaining the level and consistency of the charges in the reservoirs of both coaters.

Although the use of the two coating machines described here appears to be the only practical means of coating all of the required gages, it is recognized that specialists in the coating field may wish to propose alternative methods. The contractor wishes to emphasize that there is no reason why other methods should not be applied if there is reasonable assurance that they will work. The following are basic criteria for proposed designs:

1. The system must not depend on perfect straight-line tracking of the web.

Appendix IV, Continued

2. The system must be capable of coating one side only of webs as thin as 0.008 inches (the majority of work will be on 0.016-inch stock.)
3. The system must be capable of coating one side only of wide aluminum webs, as thick as 0.040 inches, which may contain marked variations in flatness.
4. All rolls which are to be wet must be in contact with the stock solution; "transfer-roll" systems will dry up.

H - Oven

The design of the oven shown in Drawing C-3 is tentative<sup>(6)</sup> only, and is subject to improvement or modification by the actual buyer and/or fabricator. The contractor wishes to emphasize that a careful selection of safety equipment is required for such an oven, but has not attempted to list or specify these devices. Safety equipment should be proposed by the oven manufacturer, and reviewed by the cognizant insurance companies.

The temperatures shown on the drawing are arbitrarily selected. It will undoubtedly be necessary to modify the temperature conditions, after the unit is in operation, to bring about optimum results. To this end, the entire heating system should have enough flexibility to permit wide adjustments. The objective of the builder should be a uniform temperature gradient with an adjustable slope, rather than the achievement of the actual stage temperatures shown on the drawing.

The magnitudes and directions of the air velocities within the oven should be designed to avoid distortion of the web catenary. The openings at the input and exhaust ducts should be large. The inside width of the oven should be approximately six feet, to allow free circulation around the edges of the 48-inch web.

The following design computations are intended to support the choice of air-flow rates and heat rates shown in the proposed design on Drawing No. L-4:

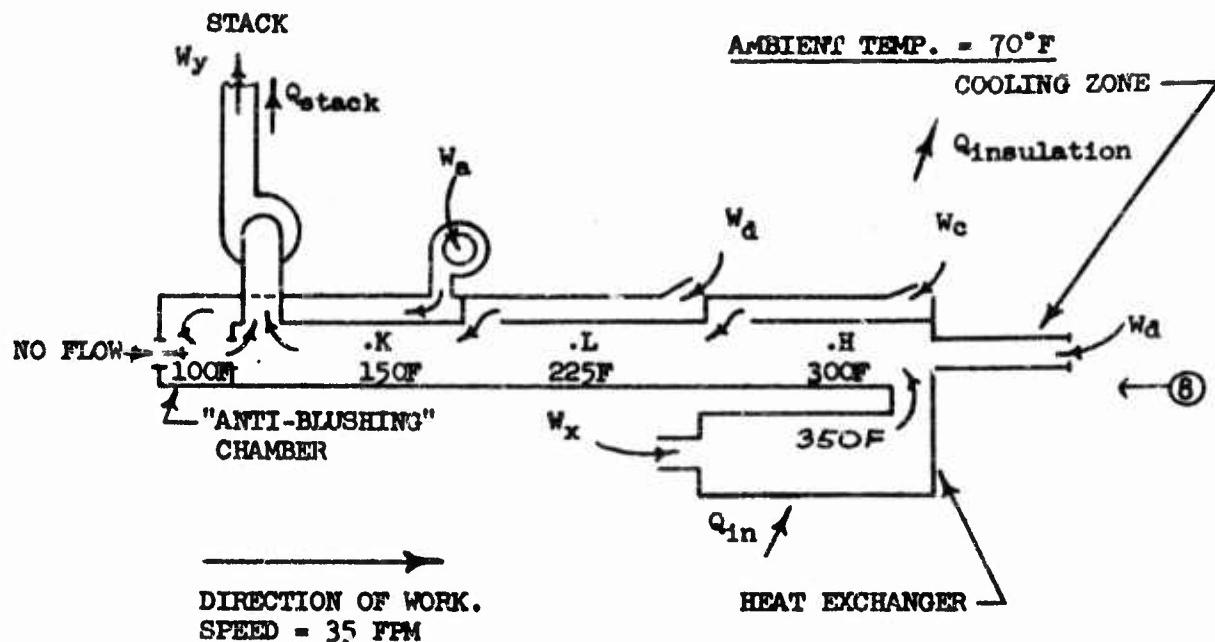
1.- Assumptions:

←⑦

- a) The general configuration and temperature locations are those shown in the following sketch:

(14)

Appendix IV, Continued



b) Maximum weight of dried adhesive coating applied in each pass = 0.003 lbs./square foot on each side.

c) Solvent: Toluol (most critical solvent in assumed mixture). (Other solvents may be ethyl alcohol, MEK, dioxane, ethylene dichloride, and secondary butanol).

d) Solids content of mix: 7 pct. (min.).

e) All solvent is removed in the oven. (Some solvent may be evaporated in the open area between the coating rolls and the oven entrance.)

f) The wet adhesive will be subject to "blushing" (pickup of condensed water vapor) unless special measures are taken to prevent it from reaching a low temperature.

g) The coating will "boil" excessively unless care is taken to prevent abrupt rises in temperature.

(15)

Appendix IV, Continued

- h) A 1.2-minute exposure to a nearly uniform temperature gradient increasing from 100°F to 300°F will give adequate drying, ←⑨ without blushing or excessive boiling.
- i) A direct, gas-fired heat exchanger may ←⑩ be used, provided that all pertinent safety devices recognized by insurance companies and responsible oven manufacturers are incorporated to preclude the possibility of explosion of either the solvent or the fuel.
- j) Insulation loss ( $Q_{insulation}$ ) is approximately 3000 BTU/min.

2 - Nomenclature:

T: temperature, deg. F.  
W: weight rate, air, lbs./min  
Q: constant-flow internal energy,  
available at 70°F (ambient),  
BTU/min.  
V: volumetric air flow rate, CFM  
  
Cp: specific heat (0.24 BTU/lb/°F for air)

3 - Design Values:

- (1) Air evacuation to remove one gallon of Toluol at "Lower Explosive Limit" ("L.E.L.") = 2360 cubic feet (at 70°F)
- (2) Evacuation safety factor = 4.
- (3) Wt. of Toluol = 7.22 lbs./gal.
- (4) Air density at 70°F = 0.075 lbs/cubic foot.

4 - Calculations:

Rate of solvent introduction:

$$\begin{aligned} \text{a) Width} \times \text{Speed} \times \text{Solids Deposited} \times \frac{\{1 - \text{solids content}\}}{\text{solids content}} \\ = (4) \text{ ft.} (20) \text{ ft/min} (.003) \text{ lbs/sq.ft.} \frac{\{1 - .07\}}{.07} \\ = 3.19 \text{ lbs/min/side} \end{aligned}$$

Total solvent introduction (both sides) =  $2 \times 3.19$

$$= 6.38 \text{ lb/min}$$

(16)

Appendix IV, Continued

b) Total evacuation required:

(1) Volumetric

$$V_y = (\text{cubic ft. of air per gallon at L.E.L}) \times (\text{Temp. correction})$$

$$\times \left( \frac{1}{\text{lbs. per gallon}} \right) \times (\text{rate of solvent introduction}) \times (\text{safety factor})$$

$$= (2360 \text{ ft}^3)(460+120) \times \left( \frac{1}{460+70} \right) \frac{\text{gal}}{7.22} \times 6.38 \text{ lbs/min} \times 4$$

$$V_y = 9130 \text{ CFM air at } 120^\circ\text{F}$$

(2) Gravimetric:

$$W_y = (\text{Volumetric rate}) \times (\text{Temp. correction}) \times (\text{density})$$

$$= 9130 \text{ ft}^3/\text{min} \times \left( \frac{460+70}{460+120} \right) \times (.075) \frac{\text{lbs}}{\text{ft}^3}$$

$$W_y = \underline{627 \text{ lbs/min}}$$

c) Stack Heat Loss:

$$Q_{\text{stack}} = W_y C_p (120-70) = 627 (0.24)(50)$$

$$\underline{Q_{\text{stack}} = 7520 \frac{\text{BTU}}{\text{MIN}}}$$

d) Heat Input:

$$Q_{\text{in}} = Q_{\text{stack}} + Q_{\text{insulation}} = 7520 + 3000$$

$$\underline{Q_{\text{in}} = \frac{10,500 \text{ BTU/min}}{(\text{or } 630,000 \text{ BTU/hr})}} \quad \leftarrow \text{⑪}$$

e) Air Weight Rates:

(1) Through heat exchanger:

$$W_x = \frac{Q_{\text{in}}}{C_p(350-70)} = \frac{10,520}{(0.24)(280)}$$

$$\underline{W_x = 157 \text{ lbs/min}} \quad \leftarrow \text{⑫}$$

(2) Through cooling stage ( $W_d$ ):

$$Q_m = Q_{\text{in}}$$

$$(W_d + W_x) C_p (300-70) = 10,520 \text{ BTU/min}$$

$$W_d = \frac{10,520 - 157}{(0.24)(230)}$$

$$= 191.3 - 157 \\ (17)$$

$$W_d = \underline{34.3 \text{ lbs/min}} \quad \leftarrow \text{⑬}$$

Appendix IV, Continued

(3) Flow through last damper ( $w_c$ ):

(One half of insulation loss assumed to occur in 300° stage)

$$Q_1 = Q_{in} - 1/2 Q_{insulation}$$

$$(w_c + w_d + w_x) C_p (225-70) = 10,520 - 1500$$

$$w_c = \frac{9020}{(0.24)(155)} = (w_d + w_x)$$

$$= 243 - (34.3 + 156.5)$$

$$w_c = \underline{51.7 \text{ lbs/min}} \quad \leftarrow \textcircled{12}$$

(4) Flow through middle damper, ( $w_b$ ):

(One fourth of heat loss assumed to occur in 225° F stage)

$$Q = Q_{in} - 3/4 Q_{insulation}$$

$$(w_b + w_d + w_x) C_p (150-70) = 10,520 - \frac{3 \times 3000}{4}$$

$$w_b = \frac{8270}{(80)(0.24)} - (51.7 + 34.3 + 156.5)$$

$$w_b = \underline{188 \text{ lbs/min}} \quad \leftarrow \textcircled{12}$$

(5) Flow through blower, into "anti-blushing" chamber ( $w_a$ ):

(One fourth of insulation loss assumed to occur in 150°F stage)

$$Q_{stack} = Q_{in} - \text{insulation loss}$$

$$(w_a + w_c + w_d + w_x)(C_p)(120-70) = 10,520 - 3000$$

$$w_a = \frac{7520}{(0.24)(50)} - (188 + 51.7 + 34.3 + 156.5)$$

$$w_a = \underline{196 \text{ lbs/min}} \quad \leftarrow \textcircled{12}$$

(6) Air Volumetric & Gravimetric Rates and Temperatures,  
Tabulated (Volumetric flows are shown on Drawing L-4):

	W lbs/min	T °F	V CFM(at temp)	Through:	$\leftarrow \textcircled{12}$
a	196	70	2610	blower	
b	188	70	2510	damper	
c	51.7	70	688	damper	
d	34.3	70	457	cooling tunnel	
x	157	70	2090	blower	
y	627	120	9130	blower	

Note: Air velocities, duct diameters, and damper openings have not been computed. Pressures throughout the oven are negative.

(18)

Appendix IV, Continued

J - Shearing and Stacking Line:

The shearing and stacking line is a separate accessory to the continuous line itself, and should preferably be purchased as a "package". Since these units are more or less standard, no drawing is included.

A line of this type normally consists of an unwind stand (a "spool" type is preferable to a "cradle" type), a "breaker" which drives and flattens the web, a "hump-table" or other device to accumulate a small amount of slack during the shearing period, a shear, and a sheet stacker. Most units operate at a speed of the order of 100 to 200 feet per minute, which would be very generous for this application. The breaker in this case need have no more than five rolls. (The last two rolls are "nip" rolls which serve to drive the web while the other rolls are staggered in order to flex the web and remove the curvature induced from the previous operation.)

The shear should be capable of cutting 75S-T6 aluminum, 0.040 inches thick and 48 inches wide. The stacker should be able to accomodate widths from 18 inches to 48 inches and should be capable of controlling the length of cut sheets within 1/32 inches from 12 inches to 144 inches.

The entire unit must be able to process the web without danger of contaminating it with lubricants, etc.. The material must not be scratched in the process.

It is suggested that the purchaser determine if the protective interleaf, introduced in the final coiling operation, can be successfully passed through the shearing and stacking operation. If not, means should be provided to collect it on a separate spool, as the coils are sheeted.

The stacked sheets must be handled with care and should be stored in a dry, cool place until bonded into sandwich assemblies.

Appendix IV, Continued

IV - TABULATION OF INDIVIDUAL COMPONENTS:  
 (Rolls, and separate accessories are listed at end)

QUANTITY	ITEM	EQUIPMENT COST	INSTALLATION* COST
2	Uncoilers, 5000# capacity 16" arbor (no brakes required)		
2	Wire Stitchers, with 25" throat		
1	Rack-driven mount for wire stitchers		
2	Mountings for 6"-dia. clamp rolls on either side of stitchers (less rolls)		
1	Bridle for 50# drag brake (less rolls)		
1	Accumulator assembly with provision for 3 fixed and 2 movable rolls (less rolls) subject to U.S.S. Royalty		
1	Bridle for 0-300# drag brake (less rolls)		
1	Alkaline spray unit (with reservoir, pump, sprays, etc.)		
1	Post-alkaline spray rinse unit		← 13
2	Sets of mounts for 6"-dia. sponge rolls, with bearings, less rolls		
1	38-ft. ceramic acid tank with hoods, stack, heaters, and steam-temperature- controlling device.		
1	Post-acid, two-stage spray rinse with recirculation, spray heads, etc.		
1	Vertical drying tunnel, direct gas-fired.		
1	Vertical air-cooling tunnel		
1	Enclosed reverse-roll coater with rolls, elevating assembly, recircu- lating system, and drive (continued)		

\* Assuming installation is within 500 miles of supplier.

Appendix IV, Continued

QUANTITY	ITEM	EQUIPMENT COST	INSTALLATION* COST
1	Enclosed squeeze-roll coater (modified veneer coater) with rolls, motor, recirculating system, and drive		
1	Forced exhaust-hood system (over coaters)		
1	Four-stage evacuated oven with direct gas-fired heat exchanger, and interlocking safety control system		
1	Four-roll drive bridle with motor, speed reducer, variable-speed drive (less rolls)		←(11)
2	Coilers, 5000# capacity, 16" arbor with motors, clutches.		
8	Sets of mounts and bearings for miscellaneous rolls		
ROLLS (12" dia., 52" long, unless otherwise noted)			
4	6"-dia. rubber-covered (clamp rolls at stitchers).		
4	6"-dia. rubber-covered "LORIG-ALIGNER" slit full-cylindrical (squeegees)		←(15)
2	Auto. self-centering (snubber type) "LORIG-ALIGNER"		
6	Slit, rubber-covered "LORIG-ALIGNER", full-cylindrical		
7	Slit, rubber-covered "LORIG-ALIGNER", narrow-bodied		
6	Narrow-bodied steel		
1	Full cylindrical stoneware, 16" dia. (with bearings and mounts)		
2	Water-cooled, hard-chrome plated, full cylindrical (with fittings, bearings, and mounts)		←(16)
	(continued)		

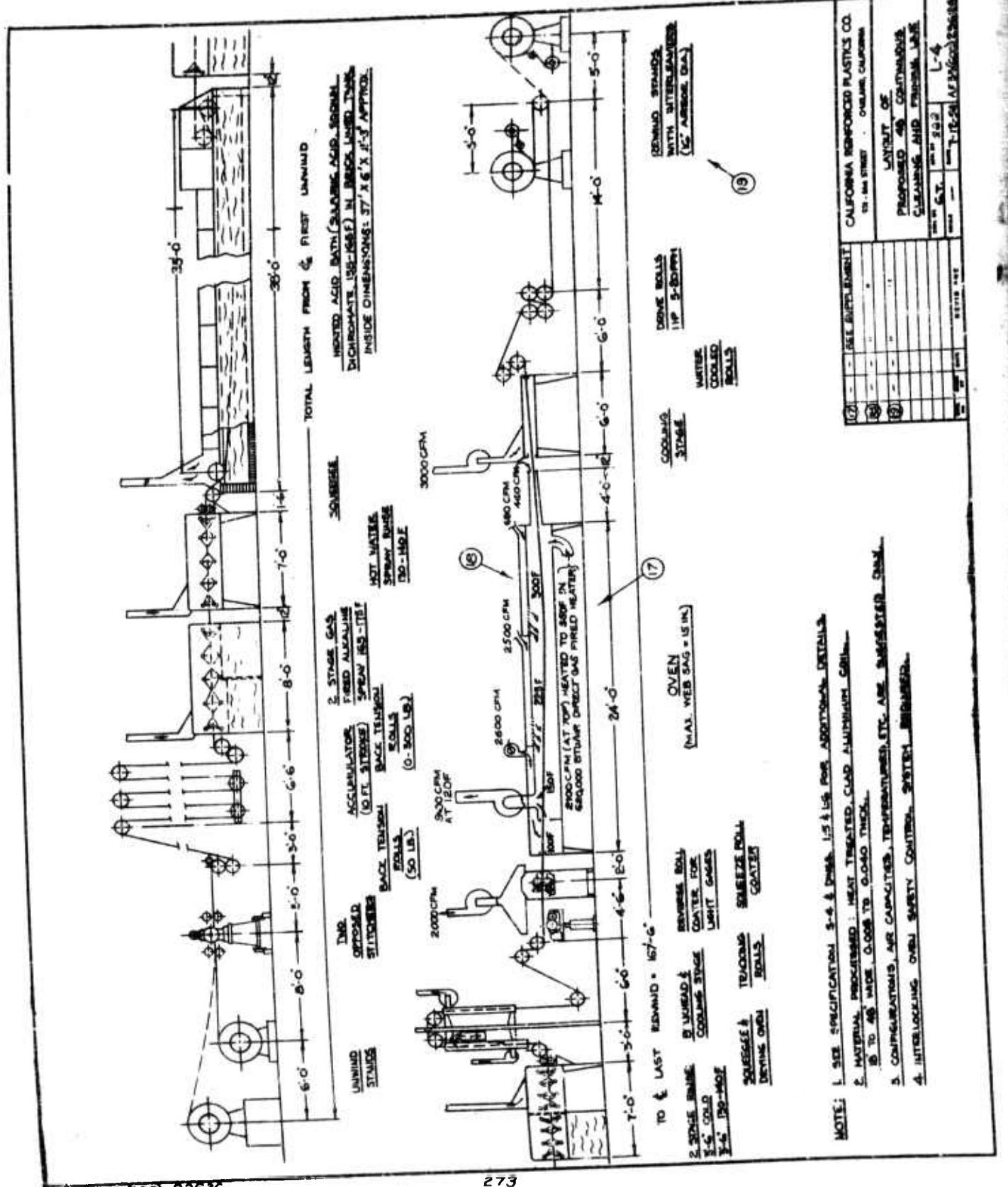
\* Assuming installation is within 500 miles of supplier

(21)

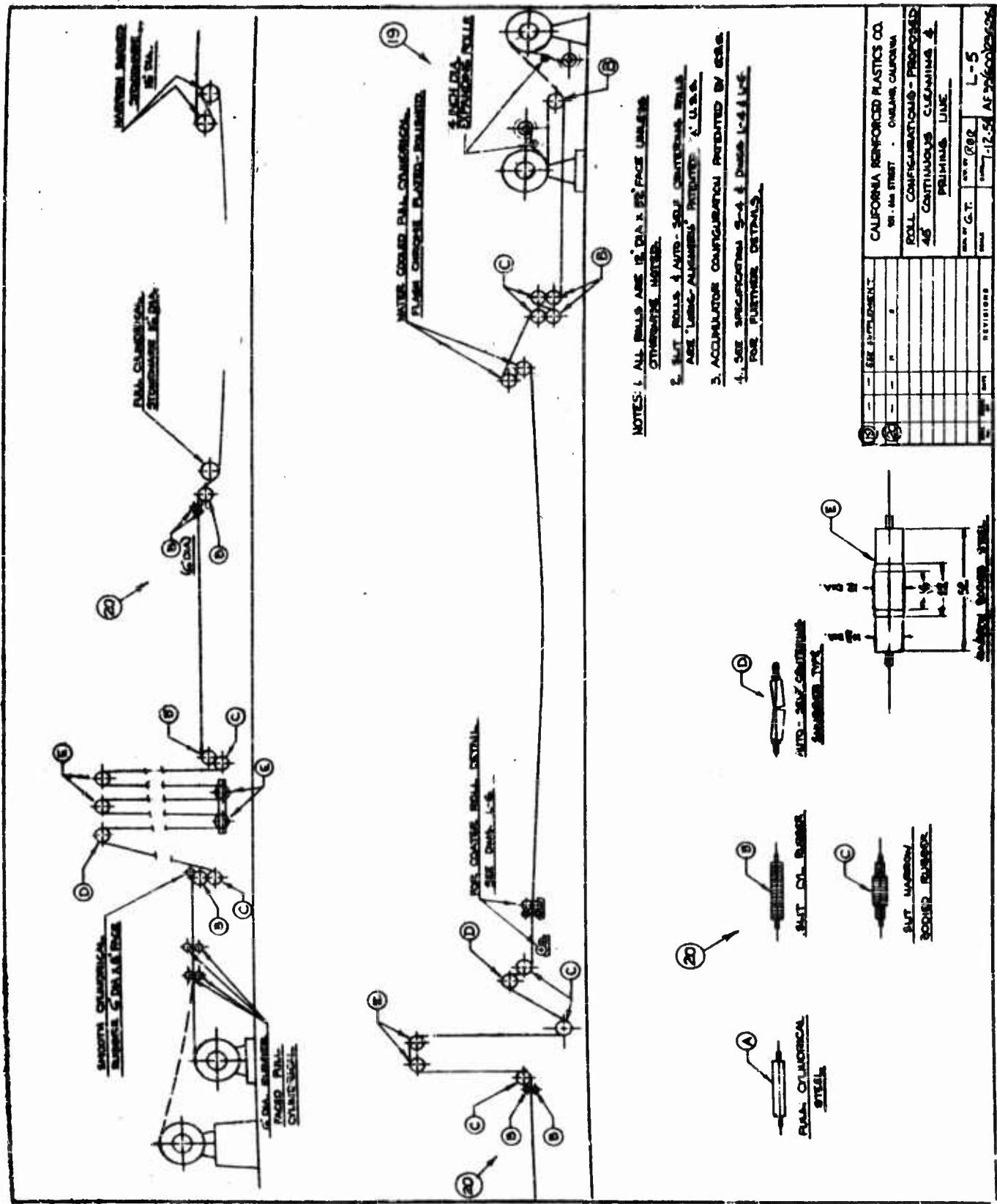
Appendix IV, Continued

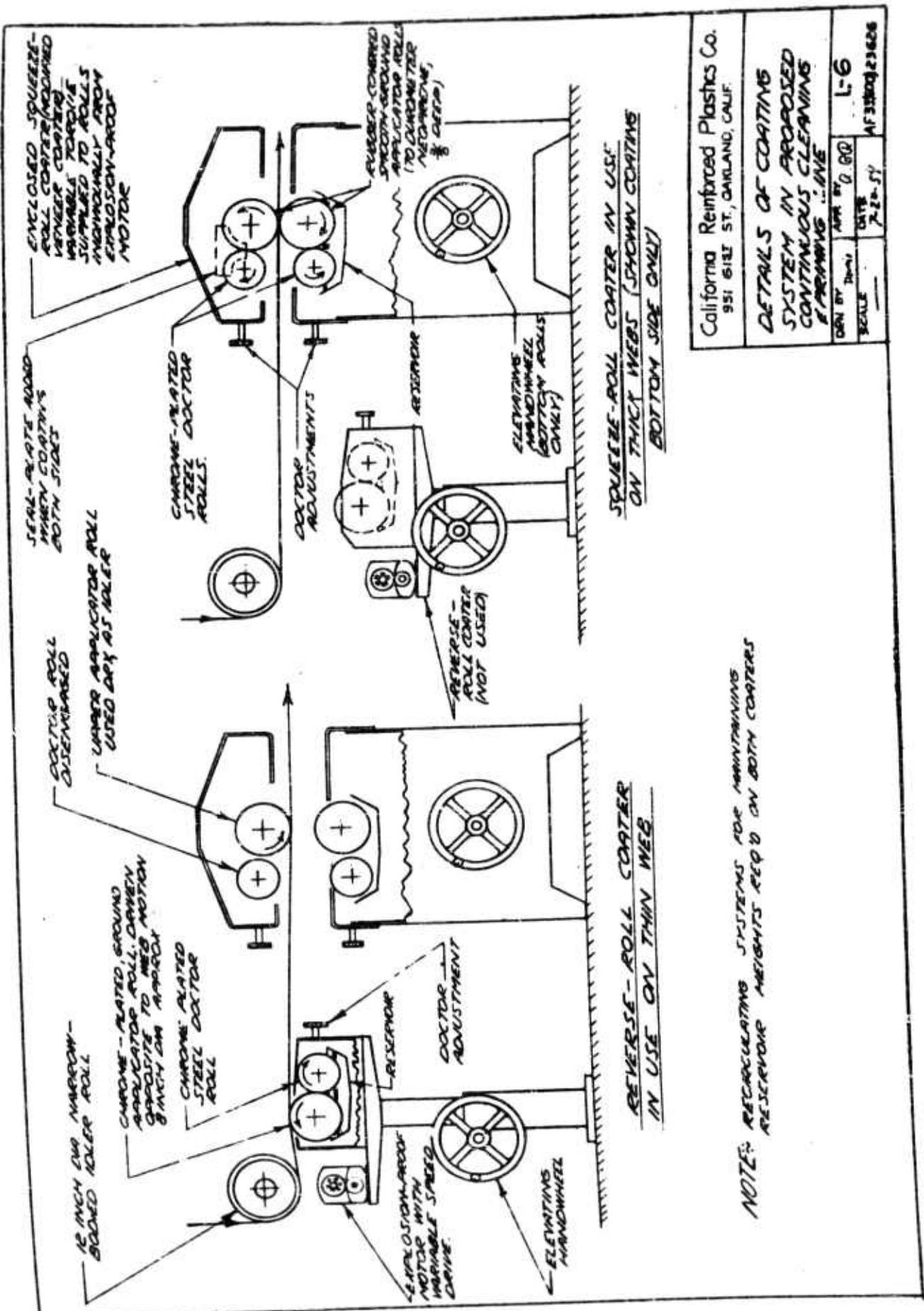
QUANTITY	ITEM	EQUIPMENT COST	INSTALLATION* COST
2	"Mount Hope" type expanding rolls, 4" dia.		
<u>ACCESSORIES TO CONTINUOUS LINE:</u>			
1	Breaking, shearing and stacking line, 48" wide, 12" to 144" long. Five-roll breaker. Capable of shearing 75S-T6, 0.040 thick at at least 50 ft./min.		
1	Stainless steel storage tank, 4000 gal. capacity		
1	Acid-resistant (metallic) pump- ing system, capable of pumping 50 GFM of hot acid at 10 ft. head		
1	Automatic sewage neutralizing system, with recording pH meter, capable of continuously neutra- lizing 20 gallons of 25 pct. sulfuric acid per hr. in stain- less steel sump		
2	Monorail hand-operated chain hoist system; 1 ton capacity (centered over line, for assembly and main- tainance)		
1	Fork-lift truck, 3-ton capacity		
1	15-H.P. steam-generating unit for acid-tank heaters		
1	Continuous hot water supply for maintaining 5 GPM at 140°F.		

\* Assuming installation is within 500 miles of supplier.



NOTE: 1. SIZE SPECIFICATION 3-450  
2. MATERIAL PROCESSED : HEAT TREATED CLAD ALUMINUM CATH.





AF33(600)-23626

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## APPENDIX V

September 30, 1954

### SUPPLEMENT TO PROPOSED SPECIFICATION S-5, MECHANIZED CORE-PRIMING AND DRYING LINE

Prepared by Hexcel Products Co., a division of  
California Reinforced Plastics Co.  
under Contract No. AF 33(600)-23626  
(This is not a Government specification)

**IMPORTANT:** The information in this supplement supersedes that in "Proposed Specification S-5", where applicable. The specification, itself, was prepared during the performance of the contract and was distributed widely among manufacturers of ovens and coating equipment, for comment and criticism. A number of important revisions were suggested by the manufacturers. Because these firms have become familiar with the original specification and have retained it in their files, it has been republished in substantially unchanged form in the final report of Contract No. AF 33(600)-23626. The important revisions have been published separately in this supplement. A number of minor typographical corrections and improvements in clarity have been made in the specification, but changes of this type have not been shown in the supplement.

The revisions contained in this supplement follow the outline of "Proposed Specification S-5". Each revision has been given a circled number which is also shown in the margin of the latest printing of the specification contained in the Final Report.

#### INTRODUCTORY MATERIAL ON FIRST PAGE.

- ① Second Paragraph - Change: "from 0.01 to 0.04 lbs/square foot ..." to read "from 0.002 to 0.04 lbs/square foot ..."
- ② Change: "...from 0.015 to 0.020 inches." to read "...approximately .025 inches."
- ③ Change: "From two to eight double passes..." to read "From one to eight double passes..."

Listing of components at bottom of first page:

- ④ Item (2): Change "Oven housing and direct, gas-fired heat exchanger..." to read "Oven housing and indirect-fired heat exchanger..."

#### I. COATER.

Add the following sentence to end of the first paragraph:

- ⑤ "A standard coating system using a roll-metering system is not suitable for the coating of honeycomb core material with viscous metal-adhesives having low-boiling solvents."
- ⑥ Add sentence to sixth paragraph, under "I", starting with "Experimental results suggest...", as follows:  
"The depth of the rubber should be from 1/4 to 3/8 inches."

Appendix V, Continued  
Supplement to Proposed Specification S-5, Continued

- (7) Eighth paragraph, starting with "The lineal speed of the roller coater...." Delete the second sentence, which reads, "It should not be necessary to use variable-speed drives" and substitute the following two sentences: "A variable-speed drive must be used to permit relatively thick, dense slices of core material to be processed at reduced speeds, in order to provide additional oven time to bring them to temperature. The speed range should be adjustable between 20 and 35 FPM.
- (8) Twelfth paragraph, starting with "The doctor gap settings under consideration....." Change "0.030 inches" to "0.020 inches".

II. OVEN:

- (9) Add the following two sentences to the end of the first paragraph: "One source of explosion hazard which should be anticipated is the possible stoppage of the coater, which might cause the honeycomb cells to become flooded with an excessive amount of adhesive from the top reservoir. In order to prevent this condition from becoming hazardous, it might be necessary to provide for an extra long, automatically controlled interval before the burners may be relighted, to allow the flooded material to pass through the oven at a reduced temperature.

Design Computations:

A. Assumptions:

- (1) Sketch: (Note: The oven temperatures shown on this drawing are now considered inadequate, since the cooling effect of the material will cause the wet surface to be at a temperature which is far below the temperature of the surrounding oven atmosphere.)

(10) Change: the temperatures at "K", "L", "M", and "HEAT EXCHANGER" from "150°", "200°", "250°", and "300°F", respectively, to "200°", "250°", "300°" and "350°F".

(11) Change: the temperature at the exhaust duct from "120°F" to "150°F".

(12) Change: "SPEED = 35 FPM" to "MAX. SPEED = 35 FPM".

Appendix V, Continued  
Supplement to Proposed Specification S-5, Continued

- (7) Eighth paragraph, starting with "The lineal speed of the roller coater...." Delete the second sentence, which reads, "It should not be necessary to use variable-speed drives" and substitute the following two sentences: "A variable-speed drive must be used to permit relatively thick, dense slices of core material to be processed at reduced speeds, in order to provide additional oven time to bring them to temperature. The speed range should be adjustable between 20 and 35 FPM.
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(12) Change: "SPEED = 35 FPM" to "MAX. SPEED = 35 FPM".

Appendix V, Continued  
Supplement to Proposed Specification S-5, Continued

- (13) (9) Change assumption reading "Thirty-second exposure to a nearly uniform temperature gradient increasing from 70°F to 250°F...." to read, "A forty-second exposure (corresponding to a maximum speed of 35 FPM through a 24-ft. oven) to a nearly uniform temperature gradient, increasing from 70°F to 300°F....."
- (14) (10) Delete the entire sentence reading, "A direct, gas fired heat exchanger....." and substitute the following:  
"An indirect-fired heat exchanger must be used to prevent the condensation of water (a product of combustion) in the coating. All pertinent safety devices recognized by insurance companies and responsible oven manufacturers must be incorporated to preclude the possibility of explosion of either solvent or fuel."
- (15) (11) Change insulation loss from 2000 BTU/min. to 3000 BTU/min.

D. Calculations:

- (16) Note: The calculations dealing with heat and air capacities in Specification "S-5" did not take into account the amount of heat required to warm the mass of the honeycomb core material. Experienced oven manufacturers have pointed out that this amount of heat becomes excessive where thick and/or heavy-density slices are processed. The most pessimistic condition would be where four-inch-thick slices of honeycomb having a density of 8 lbs./cu.ft. were processed, but this condition would be encountered so infrequently that it would not be economical to provide sufficient heat capacity to anticipate it. When slices having moderately high heat capacities are processed, the lineal speed should be reduced to approximately 20 FPM to provide additional drying time. Unusually heavy slices which were incompletely dried at a speed of 20 FPM. could be given an additional "dry" pass through the continuous oven, or could be placed in a batch oven, to supplement the original drying operation.

In general, the calculated heat input of 520,000 BTU/hr. would be inadequate, in view of the higher oven temperatures which have been found necessary, and in view of the significant amount

Appendix V, Continued  
Supplement to Proposed Specification S-5, Continued

of heat required to warm the honeycomb. The nominal figure should be increased to approximately 800,000 BTU/hr. (The heat exchanger should have a nominal capacity of one million BTU/hr.) The input air would be at a temperature of 350°F, requiring that a flow of approximately 200 lbs./minute (2700 cfm at 70°F) be passed through the heat exchanger to introduce this amount of heat into the oven tunnel.

The weight rates of cooling air, introduced through the tunnel; and through the dampers and the blower, would differ from the calculated values, but these changes are not important enough to be considered in this supplement.

There appears to be no need for automatic controls which would insure that the temperature at the exhaust duct stays at 120°F. So far as the requirements of the process are concerned, this temperature may vary from 100°F to 150°F. The conditions within the oven, when no work is passing through, should be set to provide an exhaust (stack) temperature of 150°F. The exhaust air capacity should be increased from 8000 CFM to 8500 CFM, to provide sufficient evacuation of volatiles at this increased temperature. The other equilibrium conditions in the oven should be set as follows:

1. 300°F at "H".
2. No flow through "infeed" opening.
3. 200°F approximately at "K".

It should be noted that it is not necessary to maintain a fixed temperature gradient throughout the oven at all times. As slices of honeycomb are introduced, the temperature conditions within the oven can be expected to change, and there is no justifiable reason to attempt to automatically compensate for this change.

Changes in calculations: due to increase in temperatures:

- (1) (2) Total evacuation required:
  - (a) Volumetric: Change  $V_y$  from 8000 CFM to 8500 CFM.
  - (b) Gravimetric: (Unchanged).
- (1) (3) Stack Heat Loss:  
Change  $Q_{stack}$  from 6650 BTU/min. to 10,500 BTU/min.

Appendix V, Continued  
Supplement to Proposed Specification S-5, Continued

- (19) (4) Heat Input:  
Change "Q in" from 8650 BTU/min. (or 520,000 BTU/hr.) to 13,500 BTU/min. (or 800,000 BTU/hr.)
- (20) (5) Air Weight Rates:  
(a) Change W<sub>x</sub> from 157 lbs/min to 200 lbs/min.  
(b), (c), (d), (e): Cross out existing numerical flow rates (W<sub>d</sub>, W<sub>c</sub>, W<sub>b</sub>, and W<sub>a</sub>).  
(f) Delete entire tabulation.

DRAWINGS:

- (21) C-3: Change length of heated portion of oven from "18' MINIMUM" to "24' MINIMUM". (Add six feet to other dimensions affected by change.)
- (22) Change note under oven to read as follows:  
"2700 CFM (at 70°F) HEATED TO 350°F IN INDIRECT-FIRED HEATER".
- (23) Change temperatures in oven, from left to right, from "150°F", "200°F", and "250°F" to "200°F", "250°F", and "300°F", respectively.
- (24) Delete all air flow (CFM) rates other than those at exhaust and heat exchanger.
- (25) Change speed (shown at left of coater) from "35 FPM" to "20 to 35 FPM".
- (26) Change note number 10 to read:  
"INDIRECT-FIRED HEAT EXCHANGER SHOULD BE....."
- (27) C-4: Change "Note 2" from "SPEED = 35 FPM" to read:  
"SPEED ADJUSTABLE FROM 20 TO 35 FPM."
- (28) Change "Note 6" to read: ".....0.020 INCHES....."  
rather than ".....0.030 INCHES....."

APPENDIX V, Continued

PROPOSED SPECIFICATION S-5 FOR MECHANIZED CORE-PRIMING & DRYING LINE \*

Prepared by Hexcel Products Co., a division of  
California Reinforced Plastics Co.  
under Contract No. AF 33(600)-23626  
(This is not a Government specification)

This specification is to be used in conjunction with attached Drawings C-3 and C-4.

The purpose of the proposed line is to apply prime coats of resinous metal adhesive to the surfaces of flat aluminum honeycomb core material, and to dry them in place. The coating should be consistent in unit weight, and in depth of penetration down the sides of the cell walls. The unit weight of the coating desired here is from 0.01 to 0.04 lbs/square foot (both sides), depending on the strength required in the finished sandwich composite. Optimum depth of penetration is from 0.015 to 0.020 inches. From two to eight double passes are generally required to place a given amount of adhesive prime on the core material. ←① ←② ←③

Aluminum honeycomb core material is supplied in a number of densities, ranging from 1.6 to 8.1 pounds per cubic foot, depending on the gauge of the foil and the size of the cells. Thickness is typically of the order of 1/2 inch, but flat slabs may range from 3/16 to 4 inches in thickness. Maximum standard "blanket" dimensions are currently 30 inches by 168 inches, but are expected to reach 48 inches by 144 inches within a year.

When flexed, a flat slab of honeycomb assumes a "saddle" shape rather than a uniform, singly curved bend. For this reason large, thin slabs cannot be supported locally, or at their edges only, in a continuous processing cycle. Low-density honeycomb is very susceptible to damage from handling.

Medium-production priming of honeycomb core is currently performed in ordinary, unhooded veneer coaters without conveyorization or special drying techniques. This current method lacks consistency of quality and large production capacity, wastes solvent, and creates fire hazards and unhealthy working conditions. Furthermore, the wet adhesive coat is likely to be smudged or removed locally in handling. This specification proposes requirements for the various components in an improved system, for the convenience of potential buyers and suppliers of the equipment. It is not intended to be a rigid specification, but a useful guide in the selection or design of equipment. The contractor and the Air Force cannot assume responsibility for the correct functioning of the equipment or for its safe operation.

The following components are considered necessary to the process:

- (1) Special roller-coater (suitable for use either individually, or as a component in the complete line);
- (2) Oven housing and direct, gas-fired heat exchanger, with interlocking safety equipment for both; ←④
- (3) Special driven conveyor system, incorporated in oven housing;
- (4) Non-driven cylindrical-roll conveyor tables;
- (5) Room air evacuators.

\* This specification has been partially superceded by a supplement. Circled numbers and arrows have been placed in the right-hand margins to indicate where important changes have been made.

Appendix V, Continued

Proposed Specification S-5, Continued

These components are described in detail, as follows:

I - COATER (See Drawing C-4)

The contractor has conducted extensive research on core coating variables, with metal adhesives. Excessive solvent loss from the mix and poor doctoring are the two most troublesome factors encountered when using a standard roller coater. The design of the coater with the special hooding and doctoring arrangements shown should nearly eliminate these difficulties.

←(5)

It is believed that the mechanical arrangement shown in Drawing C-4 can be incorporated in most standard veneer coaters. Notice that although the doctor rolls have been removed, the doctor-adjustment mechanisms have been retained. The locations of the blade assemblies are determined by plain nonrotating shafts, carried in the existing "doctor-roll" bearings.

Experiments have indicated that the use of a blade in preference to a roll completely eliminates the tendency of the mix to form ridges or "stripes" on the applicator roll. Furthermore, the agitation and aeration of the mix, which normally accelerate solvent loss, are reduced to a minimum when a blade is used. Doctor-blade metering on the top roll has not been tried by the contractor. It is believed that the blade can be made to form the bottom of a "side-plate" reservoir without difficulty. The drawing illustrates one possible arrangement for this reservoir system.

Although no specific evaluations of hooding were performed, the contractor feels that the use of a hooded machine is clearly justified. Parts of the hood must be easily detachable for cleaning, and "blowout" panels should be provided to minimize explosion hazards.

Means must be provided for continuously observing the height of adhesive in both pans. The following alternative feeding systems are recommended:

- (1) Gravity feed through 3/4-inch pipe regulated by accessible valve.
- (2) External lips covered with hinged trapdoors for convenient hand pouring.
- (3) Other systems, adapted to easy cleaning, and not subject to malfunction due to high viscosity, "tackiness", or low solvent boiling point. (It is believed that a pumping system may be difficult to clean).

The means for observing and controlling reservoir content should be clearly stated in the proposal.

Appendix V, Continued

Proposed Specification S-5, Continued

Experimental results suggest that smoothly ground rubber-covered applicator rolls are superior to other types. No tests were performed on the resistance to swelling of various types of rubber, but it is felt that a neoprene of 70 Durometer may give the best results. The user should anticipate swelling and should have extra rolls on hand to allow regrinding without excessive down time. ←⑥

Electrical equipment used in conjunction with the coater should be explosion-proof, and must not be enclosed within the hood.

The lineal speed of the roller coater should be synchronized with that of the conveyor discs. It should not be necessary to use variable-speed drives. ←⑦

Provision for rapid and accurate adjustment of gap heights with one control should be made. The proposal should state whether this control is calibrated or not. To afford compatibility with the conveyor pass line, only the upper roll should be adjustable vertically.

One of the two spreader rolls should be provided with adjustable relief springs to prevent damage from off-thickness materials.

The general degrees of durability, power, and precision incorporated in the coating machine should be of the same order as in a standard commercial veneer coater, in the medium-duty class. Machines in the low-price class, having light framing and small roll diameters, have been found to be generally inadequate. The power and durability requirements are not so high as to justify the modification of an ordinary machine to give "heavy-duty" service, however.

The doctor-gap settings under consideration here are of the order of 0.030 inches. In the opinion of the contractor, these settings ←⑧ will not dictate exceptionally high precision in the construction of the doctor-blade assemblies.

The requirements given here are intended to apply to machines used individually with manual feed and take-off, as well as to those used in combination with a mechanized drying system.

Most competitive coating machines have individual features which affect their utility and price. Those features not covered in this specification must be given consideration by the prospective buyer in the final selection of a machine.

II - OVEN (See Drawing C-3)

The design of the oven shown in Drawing C-3 is tentative only, and is subject to improvement or modification by the actual buyer and/or fabricator. The contractor wishes to emphasize that a careful selection of safety equipment is required for such an oven, but has not attempted to list or specify these devices. Safety equipment should be proposed by the oven manufacturer, and reviewed by the cognizant insurance companies. ←⑨

Appendix V, Continued  
Proposed Specification S-5, Continued

In general, it is necessary to avoid abrupt increases in drying temperature with the solvent system shown, in order to avoid excessive "boiling" or "frothing" of the coating. Low temperature in combination with high relative humidity will cause a condition called "blushing", in which moisture condenses in the coating itself. Blushing shows up as a milkiness or cloudiness of the coating, and is detrimental to bond strength in the finished product. It can be reduced or eliminated by warming the wet coating, reducing relative humidity, or raising the boiling point of the solvents. The contractor feels that the incorporation of a warm-air, low-velocity stage at the inlet end of the oven will preclude blushing.

The proposed minimum length of the oven is believed to be adequate, but it is not supported by accurate experimental data or computation. The user would undoubtedly find that a longer oven would require less critical conditions of use.

The temperatures shown on the drawing are arbitrarily selected. It will undoubtedly be necessary to modify the temperature conditions to bring about desired results. To this end, the entire system should be built with enough flexibility to allow a wide range of adjustment. The goal of the final design should be a uniform increasing temperature gradient with an adjustable slope, rather than the achievement of the actual stage temperatures shown on the drawing.

The magnitude and directions of the air velocities in the oven should be adjusted to avoid blowing the material off the conveyor. Areas formed by tunnels, baffles, and exhaust ducts should be made as large as possible.

The oven housing should be equipped with blowout panels which are easily removable for access to the conveyor system. (Prospective bidders should note that the conveyor system is closely integrated with the oven.)

The following are design calculations, intended to support the choice of air flow rates and heat rates shown in Drawing C-3:

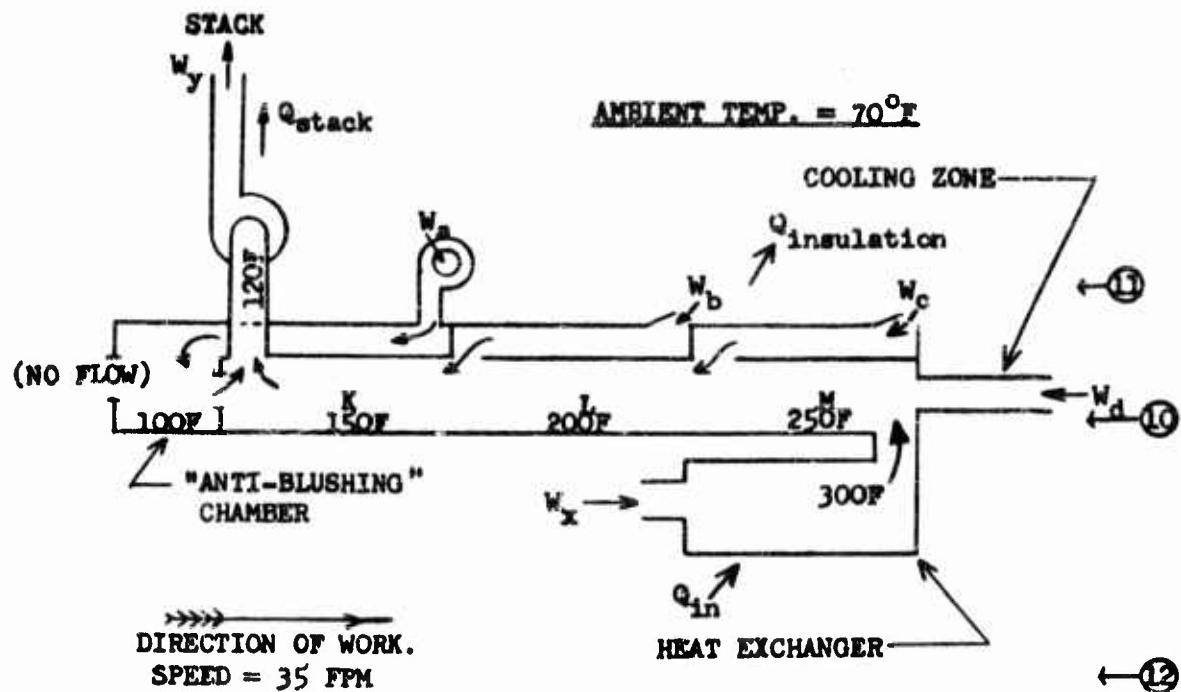
#### Design Computations

Note: These computations are intended only to serve as a guide in estimating the cost and feasibility of the proposed oven unit. Ultimate responsibility for the safety, practicability, and configuration of any actual unit is to be divided between the buyer and the builder according to their own agreement.

Appendix V, Continued  
Proposed Specification S-5, Continued

**A - Assumptions**

- (1) The general configuration and temperature locations are those shown in the figure below:



- (2) Maximum weight of dried adhesive coating, applied in each pass (both sides) = 0.010 lbs./square foot.

Note: In coating experiments conducted in the contract, this figure has never exceeded 0.005 lbs./square foot. A factor of two has been applied to allow for errors in doctor adjustment, etc.

- (3) Solvent: Toluol (other solvents may be ethyl alcohol, MEK, ethylene dichloride, and secondary butanol).

- (4) Solids content of mix: 20 pct. (min.)

- (5) All solvent is removed in the oven. (Some solvent may be evacuated in the open area between the coating rolls and the oven entrance.)

Appendix V, Continued

Proposed Specification S-5, Continued

(6) The wet adhesive will be subject to blushing (pickup of condensed water vapor) unless special measures are taken to prevent it from reaching a low temperature.

(7) The coating will "boil" excessively unless care is taken to prevent abrupt rises in temperature.

(8) It will not be necessary to remove all traces of solvent. final solids content of about 90 pct. would probably be optimum. (Over-night air dry will usually give approximately 85 pct. solids.)

(9) Thirty-second exposure to a nearly uniform temperature ← 13 gradient increasing from 70°F to 250°F will give adequate drying, without blushing or excessive boiling .

(10) A direct, gas-fired heat exchanger may be used, provided that all pertinent safety devices recognized by insurance companies and responsible oven manufacturers are incorporated, to preclude the possibility of explosion of either the solvent or the fuel. ← 14

(11) Insulation loss ( $Q_{\text{insulation}}$ ) is approximately 2000 BTU/min. ← 15

B - Nomenclature

T: temperature, deg. F.

W: weight rate, air, lbs./min.

Q: constant-flow internal energy, available at 70°F  
(ambient), BTU/min.

V: volumetric air flow rate, CFM

Cp: specific heat (0.24 BTU/lb/°F for air)

C - Design Values

(1) Air evacuation to remove one gallon of toluol at "Lower Explosive Limit ("L.E.L.") = 2360 cubic feet (at 70°F)

(2) Evacuation safety factor = 4.

(3) Wt. of toluol = 7.22 lbs./gal.

(4) Air density at 70°F = 0.075 lbs./cubic foot.

D - Calculations

(1) Rate of solvent introduction:

$$\text{Width} \times \text{Speed} \times \text{Solids Deposited} \times \frac{(1 - \text{solids content})}{(\text{solids content})}$$

$$= (4) \text{ ft.} (35) \text{ ft/min} (0.01) \text{ lbs/sq.ft.} \frac{(0.8)}{(0.2)}$$

$$= 5.6 \text{ lbs/min.}$$

← 16

Appendix V, Continued

Proposed Specification S-5, Continued

(2) Total evacuation required:

a) Volumetric

$$V_y = (\text{cubic ft. of air per gallon at L.E.L.}) \times (\text{temp. correction}) \\ \times \left( \frac{1}{\text{lbs/gal}} \right) \times (\text{rate of solvent introduction}) \times (\text{safety factor}) \\ = (2360) \text{ ft}^3 \frac{(460+120)}{(460+70)} \times \left( \frac{1}{7.22} \right) \frac{\text{gal}}{\text{lb.}} \times 5.6 \text{ lbs/min} \times 4$$

$$V_y = \underline{8000 \text{ CFM air at } 120^\circ\text{F}}$$

← 17

b) Gravimetric:

$$W_y = (\text{Volumetric rate}) \times (\text{temp. correction}) \times (\text{density}) \\ = 8000 \text{ ft}^3/\text{min} \frac{(460+70)}{(460+120)} \times (.075) \frac{\text{lbs.}}{\text{ft}^3}$$

$$W_y = \underline{552 \text{ lbs/min}}$$

(3) Stack Heat Loss:

$$Q_{\text{stack}} = W_y C_p (120-70) = 552 (.24) (50)$$

$$Q_{\text{stack}} = \underline{6650 \text{ BTU/min}}$$

← 18

(4) Heat Input:

$$Q_{\text{in}} = Q_{\text{stack}} + Q_{\text{insulation}} = 6650 + 2000$$

$$Q_{\text{in}} = \underline{8650 \text{ BTU/min}} \\ (\text{or } 520,000 \text{ BTU/hr})$$

← 19

(5) Air Weight Rates:

(a) Through heat exchanger:

$$W_x = \frac{Q_{\text{in}}}{C_p (300-70)} = \frac{8650}{.24 (230)}$$

$$W_x = \underline{377 \text{ lbs/min}}$$

← 20

(b) Through cooling stage ( $W_d$ ):

$$Q_d = Q_{\text{in}} \\ (W_d + W_x) C_p (250-70) = 8650 \text{ BTU/min} \\ W_d = \frac{8650 - (157)(.24)(180)}{(.24)(180)}$$

$$W_d = \underline{43.5 \text{ lbs/min}}$$

← 20

(c) Flow through last damper,  $W_c$

(One-half of insulation loss assumed to occur in  $250^\circ\text{F}$  stage)

$$Q_d = Q_{\text{in}} - 1/2 Q_{\text{insulation}}$$

$$(W_c + W_d + W_x) C_p (200-70) = 8650 - 1000$$

$$W_c = \frac{8650 - (157 + 43.5)(.24)(130)}{(.24)(130)}$$

$$W_c = \underline{45 \text{ lbs/min}}$$

Appendix V, Continued

Proposed Specification S-5, Continued

(d) Flow through middle damper,  $W_b$ :

(One-fourth of insulation loss assumed to occur in 200°F stage)

$$Q_k = Q_{in} - \frac{3}{4} Q_{insulation}$$

$$(W_b + W_c + W_d + W_x) C_p (150 - 70) = 8650 - 1500$$

$$W_b = \frac{7150 - (45 + 43.5 + 157)}{(.24) (80)} (.24) (80)$$

$$W_b = \underline{127 \text{ lbs/min}}$$

(e) Flow through blower, into "antiblushing" chamber,  $W_a$ :

(One-fourth of insulation loss assumed to occur in 150°F stage)

$$Q_{stack} = Q_{in} + \text{insulation loss}$$

$$(W_a + W_b + W_c + W_d + W_x) C_p (120 - 70) = 8650 - 2000$$

$$W_a = \frac{6650 - (127 + 45 + 43.5 + 157)}{(.24) (50)} (.24) (50)$$

$$W_a = \underline{181 \text{ lbs/min}}$$

(f) Air Volumetric & Gravimetric Rates and Temperatures, Tabulated: ←②  
(Volumetric flows are shown on Drawing C-3)

	W lbs/min	T °F	V CFM (at temp)	Flow Through:
a	181	70F	2400	blower
b	127	70F	1700	damper
c	45	70F	600	damper
d	43.5	70F	580	cooling tunnel
x	157	70F	2100	blower
y	552	120F	8000	blower

Note: Air velocities, duct diameters, and damper openings have not been computed. Pressures throughout the oven are negative.

### III - DRIVEN CONVEYOR

It is necessary to convey the wet material through the oven with a minimum of actual contact, and with no side interference. It is probable that the width of some slabs may run as low as 10", while others will approach 48". For this reason, a "four-and-five-wheel" conveyor system, with the inboard wheels closely spaced, is recommended.

Appendix V, Continued

Proposed Specification S-5, Continued

The contractor has tested sharp-edged rollers as a conveying medium for wet core. The results indicated that, although there was no significant loss of adhesive from the core to the discs locally, the discs did tend to accumulate some adhesive on their edges, when in contact with very fresh material. For this reason, it is recommended that a system of adjustable knives be installed for continuously cleaning the discs on the first five or six shafts. The contractor suggests that these knives consist of individual plates having a 'V' notch ground to the same angle as the discs.

The possibility of heat distortion should be anticipated in the design of the roller and cleaning-knife assemblies.

In order to reduce wet adhesion and to prevent sparking, the discs should be of brass.

In the event that the conveyor is contracted separately from the oven, a close liaison should be upheld to assure that the two are compatible. It is essential that all of the discs be accessible for inspection, and wire brushing at periodic intervals. The conveyor drive and bearings should be outboard to escape heat effects.

IV - NONDRIVEN CONVEYOR TABLES

The conveyor tables should be designed with brass or steel tubular rollers, pitched six inches apart. The run-out conveyor is inclined so as to tip the slices off the driven discs before any abrading action can take place.

It is suggested that the potential buyer eventually give consideration to the substitution of a commercial sheet stacker for the run-out conveyor. This additional mechanization would permit operation with a three-man (or possibly a two-man) crew instead of a four-man crew. Before inviting bids, the potential buyer of a stacker should determine by actual test if honeycomb can be handled in various types of units, and if damage from the "drop" is likely. A return conveyor system would be another desirable refinement.

In the actual operation of the unit, the slabs should be inverted between each pass to equalize uneven doctoring conditions in the top and bottom coating assemblies.

V - ROOM VENTILATION

The air evacuation rates shown at the overhead hoods, in Drawing C-3, are arbitrarily selected, and should be checked by a

Appendix V, Continued

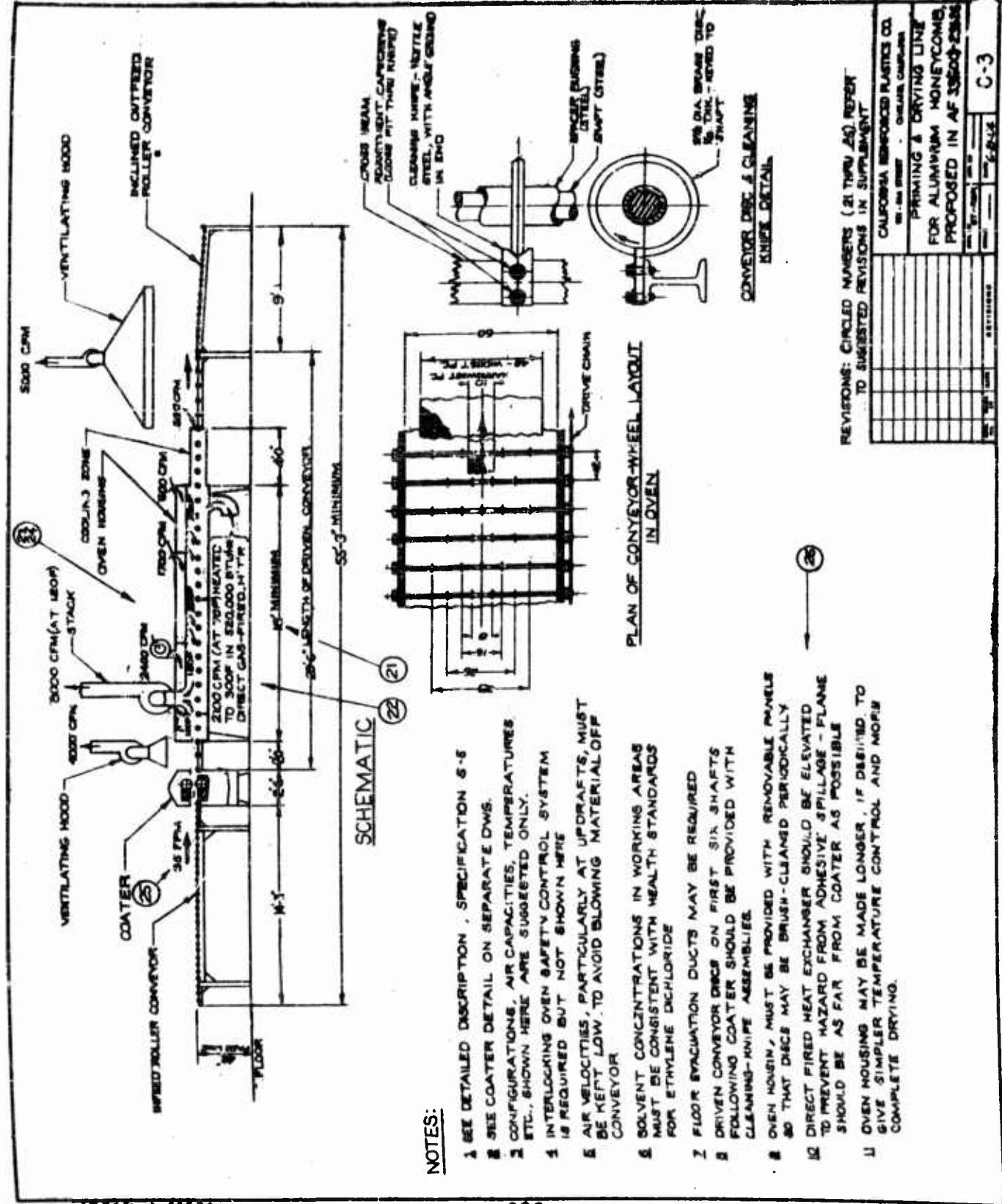
Proposed Specification S-5, Continued

qualified ventilation engin. sr. A significant amount of volatiles can be expected to evaporate in the open space between the counter and the oven. It is expected that some residual solvent may be carried with the core material out of the oven.

Because of the toxic effects of the solvent mixture (assume ethylene dichloride) ventilation must be engineered for acceptable health standards. High labor turnover, lost time from illness, high accident rates, and long rest periods will be incurred if the toxic and narcotic effects of the solvents are not fully recognized and controlled.

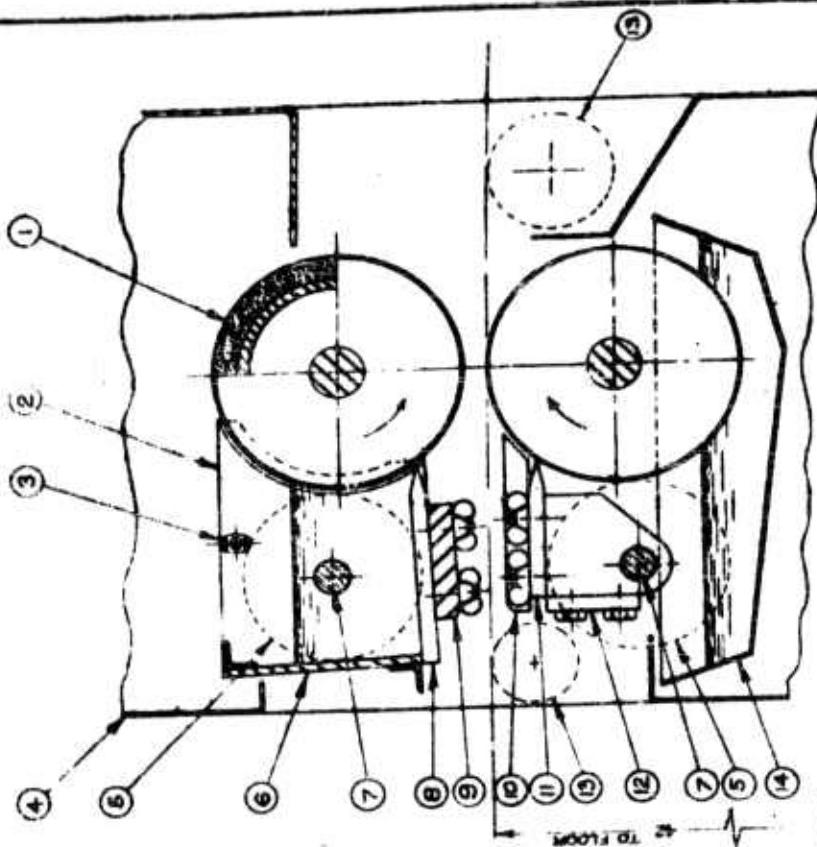
It is probable that solvent concentrations may be found in the region of the floor, dictating additional ventilation here.

A mandatory portable accessory to the core-priming line is a solvent-concentration meter, having sensitivities capable of measuring concentrations in both the "explosion" and the "health" ranges.



**VOTES:**

- 1 SEE DETAILED DESCRIPTION - SPECIFICATION & DWG.
  - 2 SEE COATER DETAIL ON SEPARATE DWG.
  - 3 CONFIGURATIONS, AIR CAPACITIES, TEMPERATURES ETC., SHOWN HERE ARE SUGGESTED ONLY.
  - 4 INTERLOCKING OVEN SAFETY CONTROL SYSTEM IS REQUIRED BUT NOT SHOWN HERE
  - 5 AIR VELOCITIES, PARTICULARLY AT UPDRAFTS, MUST BE KEPT LOW TO AVOID BLOWING MATERIAL OFF CONVEYOR
  - 6 SOLVENT CONCENTRATIONS IN WORKING AREAS MUST BE CONSISTENT WITH HEALTH STANDARDS FOR ETHYLENE DICHLORIDE
  - 7 FLOOR EVACUATION DUCTS MAY BE REQUIRED
  - 8 DRIVEN CONVEYOR DISCS ON FIRST SIX SHAFTS FOLLOWING COATER SHOULD BE PROVIDED WITH CLEANING-KNIFE ASSEMBLIES.
  - 9 OVEN HOUSING MUST BE PROVIDED WITH REMOVABLE PANEL SO THAT DISCS MAY BE BRUSH-CLEANED PERIODICALLY
  - 10 DIRECT FIRED HEAT EXCHANGER SHOULD BE ELEVATED TO PREVENT HAZARD FROM ADHESIVE SPILLAGE - FLAME SHOULD BE AS FAR FROM COATER AS POSSIBLE
  - 11 OVEN HOUSING MAY BE MADE LONGER, IF DESIRED, TO GIVE SIMPLER TEMPERATURE CONTROL AND MORE COMPLETE DRYING.

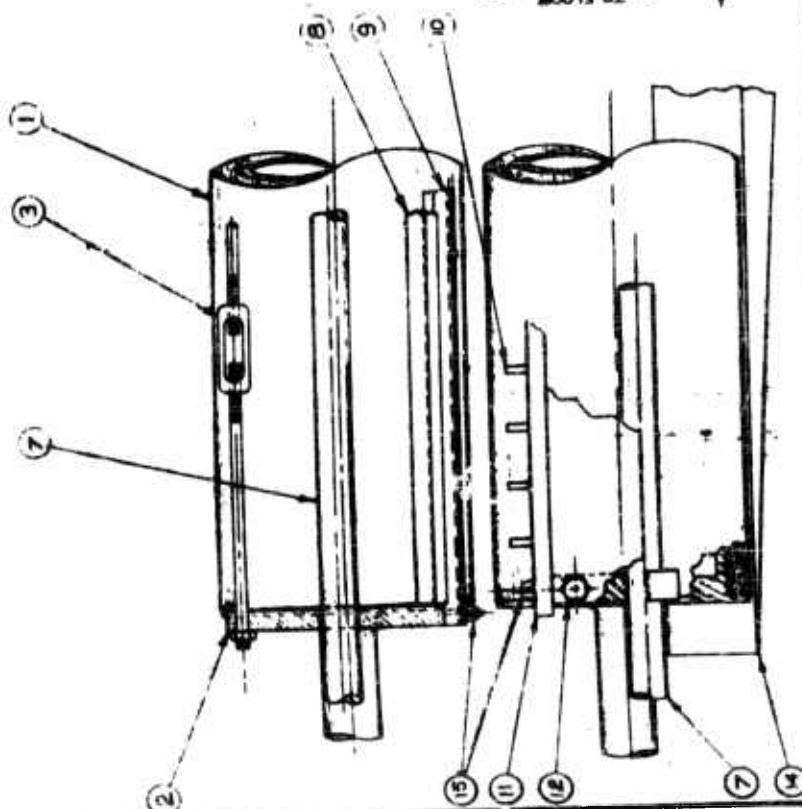


## THE MATERIALS:

BILL OF MATERIALS:	
1 SPREADER ROLLS - 6 IN. X 62 LONG APPROX. COVERED WITH 70 DUROM. NEOPRENE, GROUND SMOOTH - PLATED IN DR.	10 INFEED FINGERS
11 LOWER DOCTOR BLADE	
12 LOWER DOCTOR BLADE SUPPORT FRAME	
13 RECOMMENDED POSITIONS OF EXTER-NALLY-MOUNTED CONVEYOR ROLLS	
14 PAN RESERVOIR (STANDARD PART)	
15 WING NUTS	
16 FORMER POSITION OF DOCTOR ROLL	
17 PESTEROIR WALL	
18 STRAIGHT SHAFT IN EXISTING DOCTOR ROLL BEARINGS (NON-ROTATING)	
19 UPPER DOCTOR BLADE (H.R.S.-HARD CHROME PLATED)	
20 LOWER DOCTOR BLADE SUPPORT BAR	

**NOTES:**

1. SEE SPECIFICATION 8-5 & DNG C-3 FOR FURTHER DETAILS
2. SPEED = 35 FPM
3. DOCTOR ADJUSTMENT MECHANISM UNCHANGED
4. EXPLOSION PROOF ELECTRICAL EQUIPMENT REQUIRED - NO WIRES WITHIN HOOD
5. TOP COATING ASSEMBLY TO BE ADJUSTABLE VERTICALLY TO GIVE 0-4 INCHES WORKING GAP.
6. NORMAL DOCTOR GAP TO BE 0.030 INCHES, APPROX.
7. ONE ROLL SHOULD BE PROVIDED WITH VERTICAL RELIEF SPRINGS
8. CONFIGURATION SHOWN HERE IS SUGGESTED ONLY
9. A NUMBER OF MAINTAINING RESERVOIR LEVELS REQUIRED



## APPENDIX VI

### EXPLORATORY INVESTIGATION OF SHEAR-TENSILE CORRELATION

Although a considerable amount of data was collected in this project relating flatwise tensile strength and peel strength to various material and process parameters, it became apparent that these data in themselves were not of immediate value to the designer. Survey information revealed that many firms engaged in the manufacture of aluminum honeycomb sandwich did not directly relate the service properties of the bond, such as flexural shear strength, to bond-strength values. Although there was a general agreement that bond strength had to be above a certain level of quality to assure that shear strengths were upheld, no attempt had apparently been made to quantitatively relate bond strength to flexural shear strength.

Some manufacturers considered that the inherent strength of the adhesive formulation determined whether or not the core shear strength was developed by an adhesive bond. The quantitative studies conducted in this project definitely indicated that bond properties such as flatwise tensile strength were influenced by bond weight and a number of other factors. It seemed probable that the shear strength at the interface between the core and facings should follow the same general trends as flatwise tensile strength and that the tensile strengths and shear strengths in this plane might be in themselves very closely related.

It was decided to conduct an exploratory program, using one adhesive only, but introducing several other variables, to determine if a correlation between shear strength in the bond and bond flatwise tensile strength existed. This work was performed with "FM-47", using relatively light adhesive lines, in order to avoid failure in the core itself. The control cure in the project (5 minutes' preheat at contact pressure; 60 minutes at 345°F, 35 psi) was used on all these panels. It should be noted that the cure in itself may be a significant parameter in the correlation. Facing thickness on most of the panels was 0.051 inches; some panels were made with 0.064-inch and 0.040-inch facings. Except in the case of the 0.040-inch facings, which were alclad 75S-T6, all facings were alclad 24S-T3. Two core densities in the 1/4-inch cell size were used. In the 1/8-inch cell size, only the 8-pound (nominal) density was used. Core thickness was varied in two instances, but the balance of the cores were all 0.625 inches thick.

Sixteen panels incorporating these parameters were fabricated and tested. Flexural shear and flatwise tensile tests were performed at room temperature and 180°F. Edgewise compressive tests were performed at room temperature only.

For the flexural tests, two specimens from each panel were cut three inches by eight inches, with the ribbon direction parallel to the eight-inch dimension. All of the flexural specimens were simply

Appendix VI - Continued

supported over a six-inch span. The load was applied at midspan at a uniform rate of approximately 1,000 lbs/minute, resulting in a total loading time of approximately two to three minutes. The two support pads and the single loading pad measured one inch by three inches and 1-1/2 inches by three inches, respectively.

The testing methods used on the flatwise tensile specimens are detailed in Appendix II of this Report. From two to five one-inch-square specimens from each panel were pulled at each test temperature.

One three-inch by 2-1/2-inch edgewise compressive specimen was cut from each panel, milled square, and tested at room temperature. The load was applied over the 2-1/2 inch-wide surfaces, in a direction parallel to the core ribbons. The clamps used to restrain the ends were 7/8 inches in height.

Tests at elevated temperatures were performed with the same fixtures used in the room temperature tests. The fixtures were enclosed within an electrically heated, thermostatically controlled oven having forced air circulation. The load was applied as soon as the specimens reached test temperature, as determined by thermocouples located in the tensile specimen blocks and in the unstressed portions of the flexural shear specimens.

The values of flexural shear strength, shown in Table 30 at the end of this appendix, were obtained from the simplified formula,  
$$S_s = \frac{P}{b(h+c)}$$
, where

S<sub>s</sub> = shearing stress, psi  
P = load, lbs.  
b = specimen width, inches  
h = total panel thickness, inches  
c = h - 2f, where f = facing thickness in inches.  
(In this evaluation, c was assumed to equal core thickness before bonding.)

It was assumed that the shearing stresses developed in the horizontal interface were equal in magnitude to the shearing stresses developed within the core. Theoretically, the flexural shearing stresses in the bond, in a sandwich structure having a low-density core, tend to approach but do not equal the stresses developed in the neutral axis of the panel. In a homogeneous rectangular beam, shearing stresses would be at a maximum at the neutral axis, and would vary parabolically through the section until they reached zero at the outer fibers. In a sandwich structure which is loaded in flexure, a portion of the shearing stress is sustained by the facings. Shear stress is at a relatively high level in the plane between the core and the facings, and rises parabolically to a somewhat higher level in the neutral axis of the panel. The relative difference between the stress in

the bond and the stress in the neutral axis is influenced by the thicknesses of the core and facings, and by the density of the core. An empirical relationship between the flexural shear and the flatwise tensile strengths of the bond, of the type sought in this exploratory investigation, would undoubtedly be influenced by the dimensions of the panel.

The tabular results of the investigation are shown in Table 30 at the end of this appendix. Graphical results, in which flexural shear strength was plotted against tensile strength at the temperature in question, are shown in Figures 89, 90, 91, and 92. Figures 89 and 90 represent an 8-pound-per-cubic-foot (nominal) core density, in both the 1/8-inch and 1/4-inch cell sizes. Figures 91 and 92 represent a six-pound-per-cubic-foot density in the 1/4-inch cell size only.

The graphical results in figures 89 through 92 were adjusted to compensate for known core-density variations about each nominal density. The uncorrected "shear vs. tensile" points had not shown a correlation when plotted together. It appeared likely, however, that some of the flexural shear specimens had failed in the core material, rather than in the bond. Since the objective of the study was to determine if a relationship existed between the flexural shear strength of the bond and the flatwise tensile strength of the bond, and since flexural shear data representing core failures were not pertinent to such a determination, it was necessary to separate these data in some way from the data representing pure bond failures.

The shear specimens were first graded visually to determine if the core failures would be discerned from the bond failures. It was found that some of the failed specimens showed obvious and pronounced core damage in the form of diagonal "shear lines". A number of specimens showed no damage to the core whatsoever. A third group exhibited buckled cell walls, but the damage was not so obvious as in the case of the specimens containing "shear lines". Since the flexural shear strengths exhibited by the latter group of specimens were scattered, it was not apparent whether they represented core failures or bond failures. Visual inspection did not appear to be a reliable means of determining whether flexural shear specimens had failed in the core or in the bond.

Because the flexural shear strength of aluminum honeycomb is strongly affected by density, it seemed that some of the dispersion of the shear strength readings could be removed by adjusting the magnitudes of the readings to compensate for known variations in density. When this was done, some of the plotted points showed a tendency to level off at definite maximum shear strengths, corresponding to the inherent strengths of the cores at each nominal density. These points were then identifiable as core failures and were, therefore, not applicable to the determination of a correlation between the shear and tensile strengths of the bond. One obvious fault with this procedure was that core density corrections had to be made on all of the data, whereas the flexural shear strengths of the specimens which had failed in the bond were not influenced by core density, nor were the flatwise tensile results from the entire group. In order to make the necessary

density adjustment without misrepresenting a "shear-tensile" correlation in the bond, it was necessary to multiply the flatwise tensile strengths by the same density-adjustment factors as were used on the corresponding shear strengths. Although this practice appears unorthodox, it can be justified on the following grounds:

(1) While the shear and tensile strengths of the bonds are not influenced by core density, the data from this evaluation included an unknown number of shear failures in the core, which did require density adjustments. Discrimination among various specimens could not be used in applying the adjustment.

(2) The ratio of shear strength to tensile strength observed in each panel before an adjustment factor was applied was not changed by making the adjustment, since the two quantities were multiplied by the same number; i.e.  $\frac{(x)}{(y)} \cdot \frac{(c)}{(c)} = \frac{x}{y}$

The adjustment factors used on the points in Figures 89 through 92 were the ratios of "nominal/actual" densities. It should be noted that this correction was not entirely accurate, since the shear strength of honeycomb is not directly proportional to its density.

Before attempting to interpret the significance of the curves, it should be noted that the tensile values represented by the circled points on Figures 89 and 90 (panels 684 and 688) were believed to have been weakened in sawing. A weakening of the type has often been observed on panels having such low tensile strengths.

A straight dotted line has been drawn at a 45-degree slope on Figures 89 and 91 representing a condition in which flexural shear strength equals flatwise tensile strength. This slope, drawn arbitrarily, appears to represent the approximate relationship between flexural shear strength in the bond and flatwise tensile strength for one particular adhesive and curing schedule, when shear failure does not occur in the core. Although there are insufficient data to accurately define a correlation, there is evidence that the ability of the bond to develop the full flexural shear strength of the honeycomb core material is related to the tensile strength of the bond, in the bonding system under evaluation.

Figures 90 and 92, which represent the values of shear and tensile strength at 180°F, do not give evidence of any core failures at this temperature. The nominal 1:1 ratio, which was observed to be generally applicable between the two properties at room temperature, is obviously not in effect in the 180°F curves. It should be noted that the wide dispersion of points on these curves was at least partly attributable to the fact that temperature was adjusted as a test condition, separately on each type of specimen. It appeared that a line drawn to represent the condition in which "shear = 0.7 tensile" depicted an approximate correlation between the two properties at a temperature of 180°F. The fact that the properties are not related by the same factor at both temperatures makes it unlikely that

there is a fixed ratio between the shear and tensile strengths of the bond for all formulations, all curing times and temperatures, and all test temperatures. There is evidence, however, that at any given set of these conditions, some correlation between flexural shear strength and flatwise tensile strength exists. The recognition of the probable existence of such a correlation by designers and process engineers should assist them in relating bonding-process variables to the service requirements of the structures.

Assuming that the shear strength of an adhesive such as "FM-47" is approximately equal to its tensile strength, it would be difficult to consistently develop the full shear strength of al 1/4-.004 core material with this adhesive. Figure 3 in Section I, Part A, of this report, indicates that to develop a flatwise tensile strength of approximately 700 psi (equal to the nominal level of core shear strength available in al 1/4-.004 core), a relatively heavy bond is required. It would be almost impossible to develop the full core shear strength of either al 1/4-.004 or al 1/8-.002 core at 180°F with such an adhesive. It should be reemphasized that the data presented here are exploratory only, and are representative of only one formulation, and one curing schedule. There is no evidence to indicate that the ratios determined here would apply to other conditions.

One "rule of thumb", which has been used as a criterion for bond strength, is that the flatwise tensile strength of the bond should equal or exceed the flatwise compressive strength of the core material. This rule has its basis in the theory that a facing under edgewise compressive loading is equally inclined to "wrinkle" inward or outward, and that the stabilizing forces in either direction should be of the same magnitude. (The rule has lately been considered invalid by those who had originally proposed it.) The edgewise compressive data shown in Table 30 indicated that flatwise tensile strength, in the normal range of values, did not appear to affect the level of edgewise compressive stress developed in the facings, and that these stresses normally exceeded the yield strength of the metal. In the case of Panel No. 688, in which the flatwise tensile strength was very low, the facing stress developed in the edgewise compressive test equaled but did not exceed the yield strength of the metal, suggesting that some minimum bond strength was required to impart full stabilization to the facing. The characteristics of the failures (sketched in Table 30) showed no discernible trend as flatwise tensile strength was increased.

The results of the edgewise compressive tests cannot be construed to prove or disprove the rule that the flatwise tensile strength of the bond should equal or exceed the flatwise compressive strength of the core, for the following reasons:

1. In all of the panels in the evaluation, core compressive strength was of a high order, and in no case did the flatwise tensile strength in the bonds equal the core compressive strength, as the rule requires.

Appendix VI - Continued

2. The degree of flatness of the specimens evaluated here was optimistic in view of the flatness which is normally tolerated in the facings of flat panels made in production. Although the core was sliced by production methods with no special tolerances, there were no core splices or inserts which might cause thickness irregularities. It is possible that facings which contain normal flatness irregularities resulting from core-thickness differences, splices, etc., may require bonds having flatwise tensile strengths of the same order as the flatwise compressive strengths of the cores, to achieve optimum stabilization.

The theory of the wrinkling of the facings of sandwich construction indicates that the strength of a sandwich part loaded in edgewise compression is a function of the shear modulus of the core; not its strength in compression or shear. The mathematical analysis required to determine the adequacy of a given core material is relatively complex, even when the effects of flatness irregularities are ignored. These analyses do not in themselves indicate the absolute level of bond strength or the relationship of bond strength to core compressive strength which are required to impart full stabilization to the facings.

In general, the rule that the flatwise tensile strength of the bond should equal the compressive strength of the core appears conservative, but reasonable, on the basis of most available criteria.

It can be generally concluded from these exploratory evaluations that there should be some attempt to correlate shear strengths developed in the bond with flatwise tensile strengths in individual adhesive systems. The fact that parameters such as cell size, bond weight, and bond configuration have proven to have a definite effect upon flatwise tensile strength makes it obvious that discretion is required in choosing a bond which will develop the full shear properties of a given core material.

One fact which came to light in discussions with designers and process engineers should be mentioned here. There is a growing belief in the industry that the simplified flexural shear formula,  $S_s = \frac{P}{b(h+c)}$ ,

does not accurately depict the influence of facing thickness on the apparent shear strength of the core material. It has often been observed that cores develop lower shear strengths when lighter facings are used. (The relatively low values of apparent core shear strength in evidence on the curves tend to substantiate this belief.) There has been some criticism of the use of heavy-gage facings in the qualification of honeycomb cores. It has appeared likely that the variety of span lengths and loading systems used by various laboratories and manufacturers has contributed to discrepancies in flexural shear results. In general, longer spans appear to give more pessimistic values of core shear strength. The apparent shear strength of core materials, as determined in various

Appendix VI - Continued

tests, is sometimes downgraded by premature compressive failures under the loading pads, particularly where single-point loading is used. The effects of facing gage and loading procedure on apparent core shear strength, using the formula in question, have not been investigated in this project.

It is generally believed that the 'plate shear' test developed by Forest Products Laboratory is a more reliable and definitive test of the strength of core material than is the flexural shear test. One reason for this belief is that the effects of facing thickness are not present in the plate shear test. Most designers prefer to use flexural shear data, however, since flexural loading of the sandwich is prevalent in actual practice, and the flexural shear test requires no special bonds to be made on the specimens.

Although it is generally well known throughout the industry, it is pertinent to note here that core thickness has some influence on the apparent level of core shear strength. Thin core slices develop higher apparent core shear strengths. The extent to which this characteristic is observed in any one evaluation probably depends on the particular loading system and panel dimensions used.

## Appendix VI, Continued

TABLE 30

## EXPLORATORY DETERMINATION OF CORRELATION BETWEEN PANEL STRENGTHS AND BOND FLATWISE TENSILE STRENGTHS IN "FM-47"-BONDED HONEYCOMB SANDWICH PANELS.

**Conditions:** Factions (thickness variable) cleaned by control methods, primed, and bonded with relatively light adhesive lines ("FM-47" tape and/or liquid) to various cores (cell size, density, and thickness variable, primed and unprimed).

**Cure:** 5-minute preheat at contact pressure; one hour at 345°F., 35 psi.

**Tests:** Flatwise tensile at room temperature, and 180°F. Six-inch-span flexural test in ribbon direction on three-inch-wide specimen at room temperature and 180°F. Edgewise compression on 2-1/2 x 3-inch milled, clamped specimen, clamp height 7/8 inches, each end.

**Notes:** 1. See Figures 89 to 92 for graphical presentation of shear - tensile results.  
2. Heat tests run as specimens reached test temperature.

Panel Number	FACING		ADHESIVE LINE		CORE		TENSILE		FLEXURAL SHEAR				EDGEWISE COMPRESSION								
	Alloy (Alclad)	Thickness Inches	PSI In./Sq. In.	PSI In./Sq. In.	Core Fins (2 sides)	Nominal Core Density Lbs/Cu.Ft.	Cell Size, In.	Thickness Inches	Density Lbs/Cu.Ft.	Room Temp. Actual PSI	180°F. Actual PSI	Facing Stress PSI	Stretch of Failure (Dotted lines represent edges of clamps)								
684	248-T3	.051	.022	.012	.055	1/8-.002	.625	7.7	140**	145**	141**	54*	355	368	N	205	212	N	52,100		
688	"	"	.023	.020	.066	"	"	"	8.2	209**	204**	145**	19**	300	292	N	206	200	N	40,400	
687	"	"	.022	.013	.057	1/8-.003	"	"	6.2	210	203	147	42	225	217	N	148	143	N	50,500	
578	"	"	.080	0	.140	"	"	"	6.0	380	380	---	-	400	400	D	---	---	---	58,000	
577	"	"	.050	.009	.107	"	"	"	6.0	428	428	---	-	347	347	D	---	---	---	54,300	
703	"	"	.045	.008	.091	1/4-.004	"	"	8.3	446	430	296	35	450	433	N	190	183	N	57,300	
685	"	"	.046	.013	.101	1/4-.003	"	"	6.3	491	468	315	00	405	386	D	242	230	N	57,500	
656	758-T6	.040	.047	.008	.097	1/8-.002	"	"	7.5	529	561	371	95	510	541	D	232	246	N	82,000	
657	248-T3	.051	.047	.010	.098	"	"	"	7.9	551	559	465	71	530	538	D	276	280	N	---	
686	"	"	.047	.013	.099	1/4-.003	"	"	5.9	586	590	398	401	393	395	D	332	334	D	61,500	
653	"	.059	.049	.008	.098	1/8-.002	.375	7.1	587	661	354	398	527	592	D	267	300	D	61,600		
655	"	"	.047	.008	.095	"	".625	7.9	589	595	445	450	565	571	D	288	292	D	55,900		
654	"	"	.048	.009	.102	"	1.00	8.4	509	579	442	420	637	607	--	421	401	N	67,400		
659	"	.051	None	.054	.052	1/4-.004	.625	8.6	526	581	385	355	620	578	D	327	304	N	60,200		
658	"	"	None	.053	.051	1/8-.002	"	"	7.9	723	732	41C	415	593	600	D	308	312	N	51,100	
576	"	"	.050	.0109	.105	"	"	"	7.6	924	971	---	--	546	572	D	---	---	---	---	

\* Adjusted by ratio of Nominal Core Density to Actual Core Density. Purpose of correction is to determine by graphical means which shear specimens failed in core material. Assumed nominal densities: 1/8-0.002 = 8.0 lbs/cu.ft. 1/4-0.004 = 6.0 lbs/cu.ft. 1/4-0.003 = 6.0 lbs/cu.ft.

\*\* Flatwise tensile specimens believed to have been weakened by sawing.

\*\*\* Flexural shear failures graded by the following code: "N": no core damage observable, "D": some buckling damage to cell walls, "D!": pronounced, diagonal, "shear-lines" in cell walls.

FIGURE 89

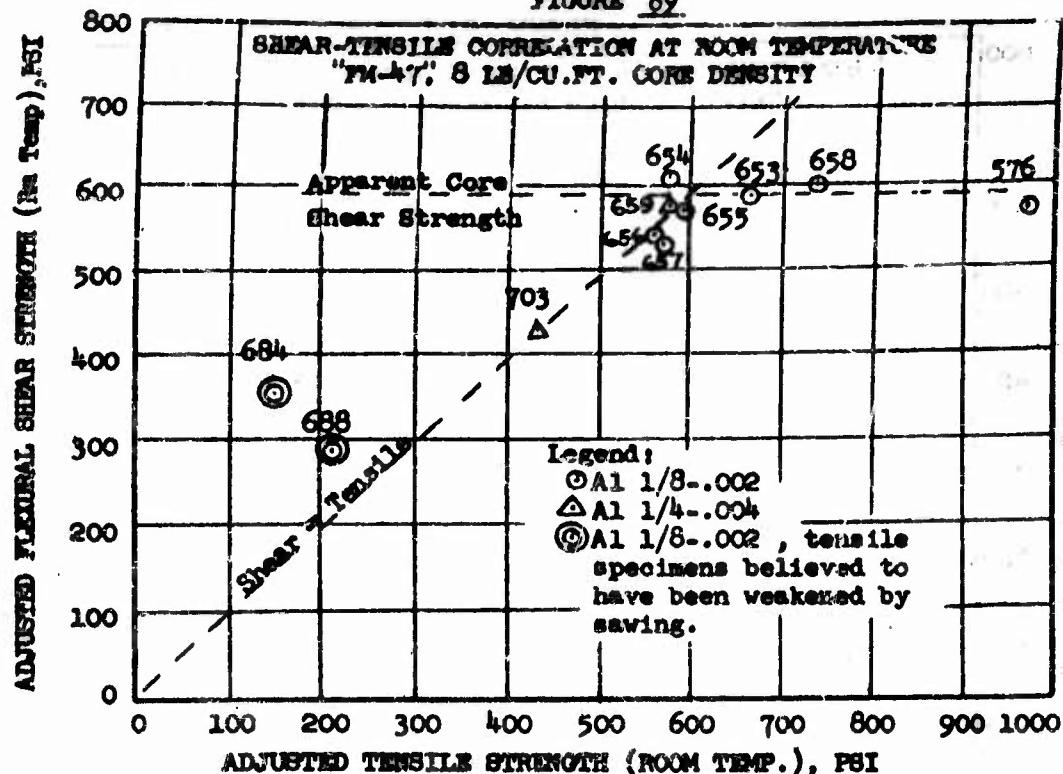
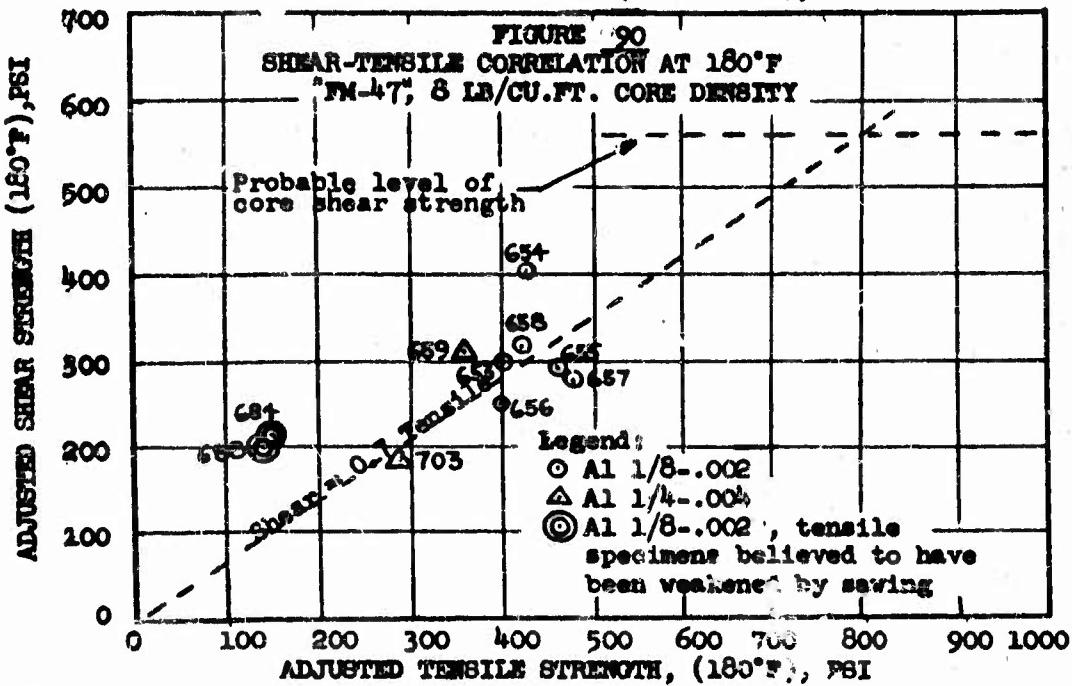


FIGURE 90



Figures 89 & 90: Exploratory comparisons of flexural shear strength ( $s_s = \frac{P}{b(h+c)}$ ) on 6-inch-spans, 3 inches wide, vs. flatwise tensile strength; room temperature and 180°F. Nominal core density = 8 lbs/cu.ft. in two cell sizes. All values adjusted by ratio of nominal/actual core densities to show correct heights of points with respect to shearing strength of core.

FIGURE 91

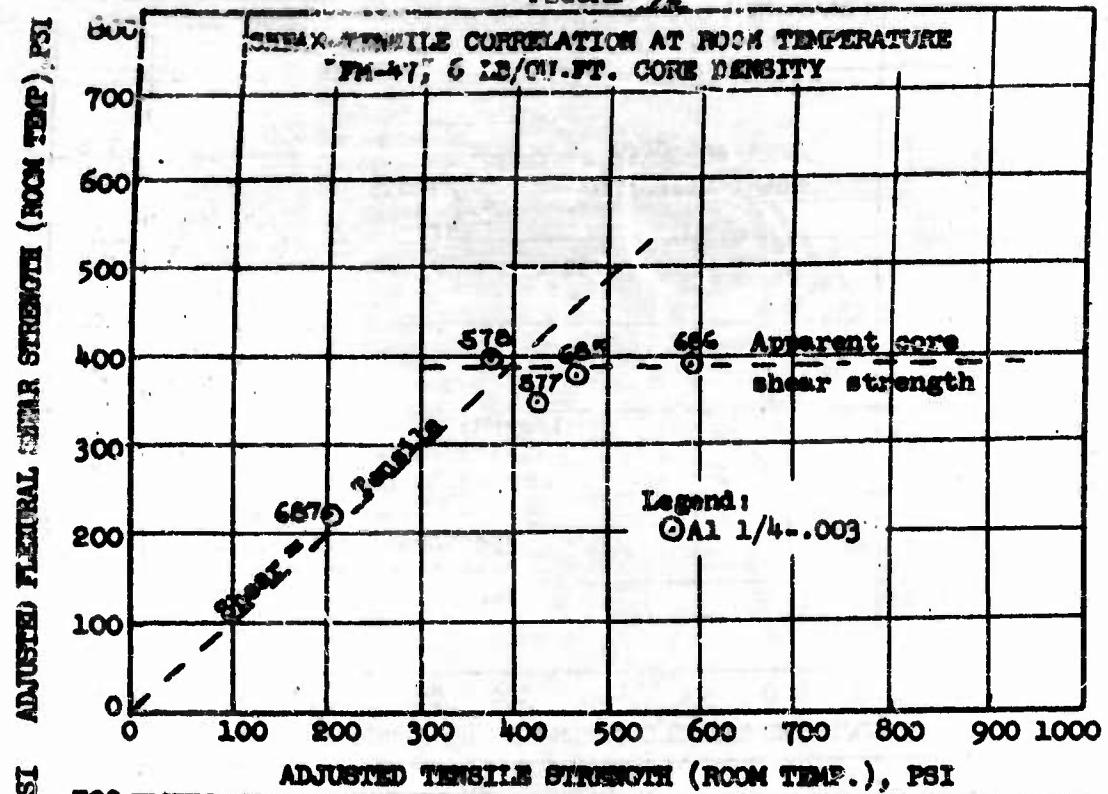
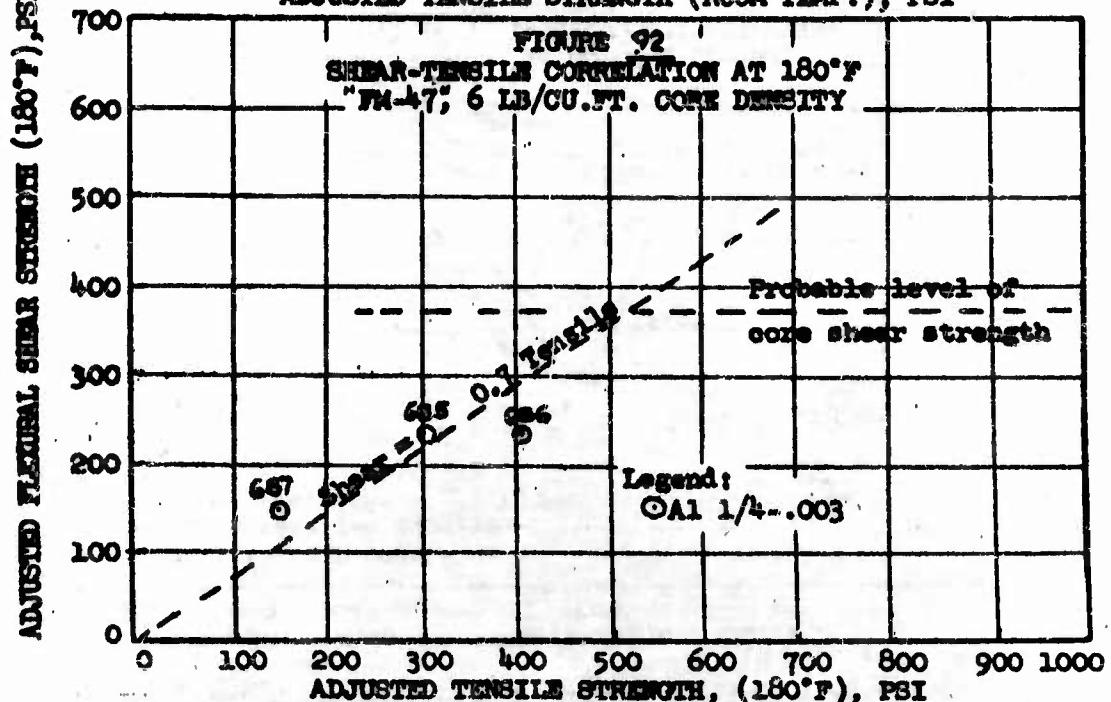


FIGURE 92



Figures 91 & 92: Exploratory comparisons of flexural shear strength ( $S_s = \frac{P}{b(h+c)}$ ) on 6-inch spans, 3 inches wide, vs. flatwise tensile strength; room temperature and 180°F. Nominal core density = 6 lbs/cu.ft. in 1/4-inch cell size. All values adjusted by ratio of nominal/actual core densities to show correct heights of points with respect to shearing strength of core

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